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With Illustrations and a Table of Physiologic Constants

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PREFACE TO THE TWELFTH EDITION.

A twelfth edition of the Compend having been called for, the author has taken the opportunity to revise some of the paragraphs and to add some new material which it is hoped will increase its usefulness to the student. While many of the changes that have been made will be found distributed throughout the body of the work, the principal changes will be found in the section relating to the cranial nerves. In this section, the newer views regarding the organ and relation of the various cranial nerves are briefly presented.

That the Compend may continue to aid the student for whom it was primarily written is the wish of

Albert P. Brubaker.

November 1, 1905.

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A COMPEND

OF

HUMAN PHYSIOLOGY.

Introduction.—An animal organism in the living condition exhibits a series of phenomena which relate to growth, movement, mentality, and reproduction. During the period preceding birth, as well as during the period included between birth and adult life, the individual grows in size and complexity from the introduction and assimilation of material from without. Throughout its life the animal exhibits a series of movements, in virtue of which it not only changes the relation of one part of its body to another, but also changes its position in space. If, in the execution of these movements, the parts are directed to the overcoming of opposing forces, such as gravity, friction, cohesion, elasticity, etc., the animal may be said to be doing work. The result of normal growth is the attainment of a physical development that will enable the animal, and, more especially, man, to perform the work necessitated by the nature of its environment and the character of its organization. In man, and probably in lower animals as well, mentality manifests itself as intellect, feeling, and volition. At a definite period in the life of the animal it reproduces itself, in consequence of which the species to which it belongs is perpetuated.

The study of the phenomena of growth, movement, mentality, and reproduction constitutes the science of Animal Physiology. But as these general activities are the resultant of and dependent on the special activities of the individual structures of which an animal body is composed, Physiology in its more restricted and generally accepted sense is the science which investigates the actions or functions of the individual organs and tissues of the body and the physical and chemic conditions which underlie and determine them.

This may naturally be divided into:

1. *Special physiology,* the object of which is a study of the vital phenomena or functions exhibited by the organs of any individual animal.
2. *Comparative physiology,* the object of which is a comparison of the vital phenomena or functions exhibited by the organs of two or more animals, with a view to unfolding their points of resemblance or dissimilarity.

Human physiology is that department of physiologic science which has for its object the study of the functions of the organs of the human body in a state of health.

Inasmuch as the study of function, or physiology, is associated with and dependent on a knowledge of structure, or anatomy, it is essential that the student should have a general acquaintance not only with the structure of man, but with that of typical forms of lower animal life as well.

If the body of any animal be dissected, it will be found to be composed of a number of well-defined structures, such as heart, lungs, stomach, brain, eye, etc., to which the term organ was originally applied, for the reason that they were supposed to be instruments capable of performing some important act or function in the general activities of the body. Though the term organ is usually employed to designate the larger and more familiar structures just mentioned, it is equally applicable to a large number of other structures which, though possibly less obvious, are equally important in maintaining the life of the individual—*e. g.,* bones, muscles, nerves, skin, teeth, glands, blood-vessels, etc. Indeed, any complexly organized structure capable of performing some function may be described as an organ. A description of the various organs which make up the body of an animal, their external form, their internal arrangement, their relations to one another, constitutes the science of ANIMAL ANATOMY.

This may naturally be divided into:

1. *Special anatomy,* the object of which is the investigation of the construction, form, and arrangement of the organs of any individual animal.
2. *Comparative anatomy,* the object of which is a comparison of the organs of two or more animals, with a view to determining their points of resemblance or dissimilarity.

If the organs, however, are subjected to a further analysis, they can be resolved into simple structures, apparently homogeneous, to which the name tissue has been given—*e. g.*, epithelial, connective, muscle, and nerve tissue. When the tissues are subjected to microscopic analysis, it is found that they are not homogeneous in structure, but composed of still simpler elements, termed cells and fibers. The investigation of the internal structure of the organs, the physical properties and structure of the tissues, as well as the structure of their component elements, the cells and fibers, constitutes a department of anatomic science known as HISTOLOGY, or as it is prosecuted largely with the microscope, MICROSCOPIC ANATOMY.

Human anatomy is that department of anatomic science which has for its object the investigation of the construction of the human body.

GENERAL STRUCTURE OF THE ANIMAL BODY.

The body of every animal, from fish to man, may be divided into—

1. An axial and
2. An appendicular portion. The axial portion consists of the head, neck, and trunk; the appendicular portion consists of the anterior and posterior limbs or extremities.

The **axial portion** of all mammals, to which class man zoölogically belongs, as well as of all birds, reptiles, amphibians, and osseous fish, is characterized by the presence of a bony, segmented axis, which extends in a longitudinal direction from before backward, and which is known as the vertebral column or backbone. In virtue of the existence of this column all the class of animals just mentioned form one great division of the animal kingdom, *the Vertebrata.*

Each segment, or vertebra, of this axis consists of—

1. A solid portion, known as the body or centrum, and
2. A bony arch arising from the dorsal aspect and surmounted by a spine-like process.

At the anterior extremity of the body of the animal the vertebræ are variously modified and expanded, and, with the addition of new elements, form the skull; at the posterior extremity they rapidly diminish in size, and terminate in man in a short, tail-like process. In many animals, however, the vertebral column extends for a considerable distance beyond the trunk into the tail. The vertebral column may be regarded as the foundation element in the plan of organization of all the higher animals and the center around which the rest of the body is developed and arranged with a certain degree of conformity. In all vertebrate animals the bodies of the segments of the vertebral column form a partition which serves to divide the trunk of the body into two cavities—viz., the dorsal and the ventral.

The **dorsal cavity** is found in the head. Its walls are not only in the trunk, but also formed partly by the arches which arise from the posterior or dorsal surface of the vertebræ and partly by the bones of the skull. If a longitudinal section be made through the center of the vertebral column, and including the head, the dorsal cavity will be observed running through its entire extent. (See Fig. 1.) Though for the most part it is quite narrow, at the anterior extremity it is enlarged and forms the cavity of the skull. This cavity is lined by a membranous canal, the neural canal, in which is contained the brain and the neural or spinal cord. Through openings in the sides of the dorsal cavity nerves pass out which connect the brain and spinal cord with all the structures of the body.

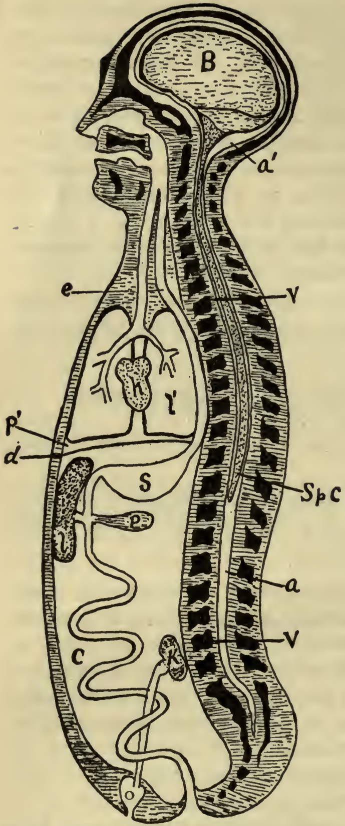


Fig. 1.—Diagrammatic Longitudinal Section of the Body.

V,V. Bodies of the vertebræ which divide the body into the dorsal and ventral cavities. *a, a′*. The dorsal cavity. C, *p′*. The abdominal and thoracic divisions of the ventral cavity, separated from each other by a transverse muscular partition, the diaphragm *d*. B. The brain. Sp. C. The spinal cord. *e*. The esophagus. S. The stomach, from which continues the intestine to the opening of the posterior portion of the body. *l*. The liver. *p*. The pancreas. *k*. The kidney. o. The bladder. *l′*. The lungs. *h*. The heart.

The **ventral cavity** is confined mainly to the trunk of the body. Its walls are formed by muscles and skin, strengthened in most animals by bony arches, the ribs. Within the ventral cavity is contained a musculo-membranous tube or canal known as the alimentary or food canal, which begins at the mouth on the ventral side of the head, and, after passing through the neck and trunk, terminates at the posterior extremity of the trunk at the anus. It may be divided into mouth, pharynx, esophagus, stomach, small and large intestines.

In all mammals the ventral cavity is divided by a musculo-membranous partition into two smaller cavities, the thorax and abdomen. The former contains the lungs, heart and its great blood-vessels, and the anterior part of the alimentary canal, the gullet or esophagus; the latter contains the continuation of the alimentary canal—that is, the stomach and intestines—and the glands in connection with it, the liver and pancreas. In the posterior portion of the abdominal cavity are found the kidneys, ureters, and bladder, and in the female the organs of reproduction. The thoracic and abdominal cavities are each lined by a thin serous membrane, known, respectively, as the pleural and peritoneal membranes, which, in addition, are reflected over the surfaces of the organs contained within them. The alimentary canal and the various cavities connected with it are lined throughout by a mucous membrane. The surface of the body is covered by the skin. This is composed of an inner portion, the derma, and an outer portion, the epidermis. The former consists of fibers, blood-vessels, nerves, etc.; the latter of layers of scales or cells. Embedded within the skin are numbers of glands, which exude, in the different classes of animals, sweat, oily matter, etc. Projecting from the surface of the skin are hairs, bristles, feathers, claws. Beneath the skin are found muscles, bones, blood-vessels, nerves, etc.

The **appendicular portion** of the body consists of two pairs of symmetric limbs, which project from the sides of the trunk, and which bear a determinate relation to the vertebral column. They consist fundamentally of bones, surrounded by muscles, blood-vessels, nerves and lymphatics. The limbs, though having a common plan of organization, are modified in form and adapted for prehension and locomotion in accordance with the needs of the animal.

Anatomic Systems.—All the organs of the body which have certain peculiarities of structure in common are classified by anatomists into systems—*e. g.,* the bones, collectively, constitute the bony or osseous system; the muscles, the nerves, the skin, constitute, respectively, the muscular, the nervous, and the tegumentary systems.

Physiologic Apparatus.—More important from a physiologic point of view than a classification of organs based on similarities of structure is the natural association of two or more organs acting together for the accomplishment of some definite object, and to which the term physiologic apparatus has been applied. While in the community of organs which together constitute the animal body each one performs some definite function, and the harmonious coöperation of all is necessary to the life of the individual, everywhere it is found that two or more organs, though performing totally distinct functions, are coöperating for the accomplishment of some larger or compound function in which their individual functions are blended—*e. g.,* the mouth, stomach, and intestines, with the glands connected with them, constitute the *digestive apparatus,* the object or function of which is the complete digestion of the food. The capillary blood-vessels and lymphatic vessels of the body, and especially those in relation to the villi of the small intestine, constitute the *absorptive apparatus,* the function of which is the introduction of new material into the blood. The heart and blood-vessels constitute the *circulatory apparatus,* the function of which is the distribution of blood to all portions of the body. The lungs and trachea, together with the diaphragm and the walls of the chest, constitute the *respiratory apparatus,* the function of which is the introduction of oxygen into the blood and the elimination from it of carbon dioxid and other injurious products. The kidneys, the ureters, and the bladder constitute the *urinary apparatus.* The skin, with its sweat-glands, constitutes the *perspiratory apparatus,* the functions of both being the excretion of waste products from the body. The liver, the pancreas, the mammary glands, as well as other glands, each form a *secretory apparatus* which elaborates some specific material necessary to the nutrition of the individual. The functions of these different physiologic apparatus—*e. g.,* digestion, absorption of food, elaboration of blood, circulation of blood, respiration, production of heat, secretion, and excretion—are classified as *nutritive functions,* and have for their final object the preservation of the individual.

The nerves and muscles constitute the *nervo-muscular apparatus,* the function of which is the production of motion. The eye, the ear, the nose, the tongue, and the skin, with their related structures, constitute, respectively, the *visual, auditory, olfactory, gustatory,* and *tactile apparatus,* the function of which, as a whole, is the reception of impressions and the transmission of nerve impulses to the brain, where they give rise to visual, auditory, olfactory, gustatory, and tactile sensations.

The brain, in association with the sense organs, forms an apparatus related to mental processes. The larynx and its accessory organs—the lungs, trachea, respiratory muscles, the mouth and resonant cavities of the face—form the *vocal* and *articulating apparatus,* by means of which voice and articulate speech are produced. The functions exhibited by the apparatus just mentioned—viz., motion, sensation, language, mental and moral manifestations—are classified as *functions of relation,* as they serve to bring the individual into conscious relationship with the external world.

The ovaries and the testes are the essential reproductive organs, the former producing the germ-cell, the latter the spermatic element; together with their related structures,—the fallopian tubes, uterus, and vagina in the female, and the urogenital canal in the male,—they constitute the *reproductive apparatus* characteristic of the two sexes. Their coöperation results in the union of the germ-cell and spermatic element and the consequent development of a new being. The function of reproduction serves to perpetuate the species to which the individual belongs.

The animal body is therefore not a homogeneous organism, but one composed of a large number of widely dissimilar but related organs. But as all vertebrate animals have the same general plan of organization, there is a marked similarity both in form and structure among corresponding parts of different animals. Hence it is that in the study of human anatomy a knowledge of the form, construction, and arrangement of the organs in different types of animal life is essential to its correct interpretation; also it is that in the investigation and comprehension of the complex problems of human physiology a knowledge of the *functions* of the organs as they manifest themselves in the different types of animal life is indispensable. As many of the functions of the human body are not only complex, but the organs exhibiting them are practically inaccessible to investigation, we must supplement our knowledge and judge of their functions by analogy, by attributing to them, within certain limits, the functions revealed by experimentation upon the corresponding but simpler organs of lower animals. This experimental knowledge corrected by a study of the clinical phenomena of disease and the results of post-mortem investigations, forms the basis of modern human physiology.

CHEMIC COMPOSITION OF THE HUMAN BODY.

Since it has been demonstrated that every exhibition of functional activity is associated with changes of structure, it has been apparent that a knowledge of the chemic composition of the body, not only when in a state of rest, but to a far greater degree when in a state of activity, is necessary to a correct understanding of the intimate nature of physiologic processes Though the analysis of the dead body is comparatively easy, the determination of the successive changes in composition of the living body is attended with many difficulties. The living material, the bioplasm, is not only complex and unstable in composition, but extremely sensitive to all physical and chemic influences. The methods, therefore, which are employed for analysis destroy its composition and vitality, and the products which are obtained are peculiar to dead rather than to living material.

Chemic analysis, therefore, may be directed—

1. To the determination of the composition of the dead body.
2. To the determination of the successive changes in composition which the living bioplasm undergoes during functional activity.

A chemic analysis of the dead body, with a view to disclosing the substances of which it is composed, their properties, their intimate structure, their relationship to one another, constitutes what might be termed CHEMIC ANATOMY. An investigation of the living material and of the successive changes it undergoes in the performance of its functions constitutes what has been termed CHEMIC PHYSIOLOGY or PHYSIOLOGIC CHEMISTRY.

By chemic analysis the animal body can be reduced to a number of liquid and solid compounds which belong to both the inorganic and organic worlds. These compounds, resulting from a proximate analysis, have been termed proximate principles. That they may merit this term, however, they must be obtained in the form under which they exist in the living condition. The organic compounds consist of representatives of the carbohydrate, fatty, and proteid groups of organic bodies; the inorganic compounds consist of water, various acids, and inorganic salts.

The compounds or proximate principles thus obtained can be further resolved by an ultimate analysis into a small number of chemic elements which are identical with elements found in many other organic as well as inorganic compounds. The different chemic elements which are thus obtained, and the percentage in which they exist in the body, are as follows—viz., oxygen, 72 per cent.; hydrogen, 9.10; nitrogen, 2.5; carbon, 13.50; phosphorus, 1.15; calcium, 1.30; sulphur, 0.147; sodium, 0.10; potassium, 0.026; chlorin, 0.085; fluorin, iron silicon, magnesium, in small and variable amounts.

THE CARBOHYDRATES.

The carbohydrates constitute a group of organic bodies, consisting mainly of starches and sugars, having their origin for the most part in the vegetable world. In many respects they are closely related, and by appropriate means are readily converted into one another. In composition they consist of the elements carbon, hydrogen, and oxygen. As their name implies, the hydrogen and oxygen are present in the majority of these compounds in the proportion to form water, or as 2:1. The molecule of the carbohydrates just mentioned consists of either *six* atoms of carbon or a multiple of six; in the latter case the quantity of hydrogen and oxygen taken up by the carbon is increased, though the ratio remains unchanged.

The carbohydrates may be divided into three groups—viz.: (1) *Amyloses,* including starch, dextrin, glycogen, and cellulose; (2) *dextroses,* including dextrose, levulose, galactose; (3) *saccharoses,* including saccharose, lactose, and maltose. According to the number of carbon atoms entering into the second group (six), they are frequently termed monosaccharids; those of the third group, disaccharids—twice six; those of the first group, polysaccharids—multiples of six.

Though but few of the members of the carbohydrate group are constituents of the human body, yet on account of their importance as foods, and their relation to one another, a few of their chemic features will be stated in this connection.

1. **AMYLOSES,** $(C_6H_{10}O_5)n$.

Starch is widely distributed in the vegetable world, being abundant in the seeds of the cereals, leguminous plants, and in the tubers and roots of some vegetables. It occurs in the form of microscopic granules, which vary in size, shape, and appearance, according to the plant from which they are obtained. Each granule presents a nucleus, or hilum, around which is arranged a series of eccentric rings, alternately light and dark. The granule consists of an envelope and stroma of cellulose, containing in its meshes the true starch material—*granulose.* Starch is insoluble in cold water and alcohol. When heated with water up to 70° C., the granules swell, rupture, and liberate the granulose, which forms an apparent solution; if present in sufficient quantity, it forms a gelatinous mass termed starch paste. On the addition of iodin, starch strikes a characteristic deep blue color; the compound formed—iodid of starch—is weak, and the color disappears on heating, but reappears on cooling.

Boiling starch with dilute sulphuric acid (twenty-five per cent.) converts it into dextrose. In the presence of vegetable diastase or animal ferments, starch is converted into maltose and dextrose, two forms of sugar.

Dextrin is a substance formed as an intermediate product in the transformation of starch into sugar. There are at least two principal varieties—*erythrodextrin,* which strikes a red color with iodin, and *achroödextrin,* which is without color when treated with this reagent. In the pure state dextrin is a yellow-white powder, soluble in water. In the presence of animal ferments erythrodextrin is converted into maltose.

Glycogen is a constituent of the animal liver, and, to a slight extent, of muscles and of tissues generally. In the tissues of the embryo it is especially abundant. When obtained in a pure state it is an amorphous, white powder. It is soluble in water, forming an opalescent solution. With iodin it strikes a port-wine color. In some respects it resembles starch, in others dextrin. Like vegetable starch, glycogen or animal starch can be converted by dilute acids and ferments into sugar (maltose).

Cellulose is the basis material of the more or less solid framework of plants. It is soluble only in an ammoniacal solution of cupric oxid, from which it can be precipitated by acids. It is an amorphous powder; dilute acids can convert it into dextrose.

2. DEXTROSES, $C_6H_{12}O_6$.

Dextrose, glucose, or **grape-sugar** is found in grapes, most sweet fruits, and honey, and as a normal constituent of liver, blood, muscles, and other animal tissues. In the disease diabetes mellitus it is found also in the urine.

When obtained from any source, it is soluble in water and in hot alcohol, from which it crystallizes in six-sided tables or prisms. As usually met with, it is in the form of irregular, warty masses. It is sweet to the taste; less so, however, than cane sugar. It is dextrorotary, turning the plane of polarized light to the right. In alkaline solutions dextrose absorbs oxygen, and hence in the presence of metallic salts, copper, bismuth, silver, etc., it acts as a reducing agent. On this property the various tests for dextrose, as well as other sugars which have the same property, are based.

Fehling's Test.—The solution usually employed for both qualitative and quantitative purposes is a solution of cupric hydroxid made alkaline by an excess of sodium or potassium hydroxid, with the addition of sodium and potassium tartrate. This solution, originally suggested by Fehling, bears his name. It is made by dissolving cupric sulphate 34.64 grams, potassium hydroxid 125 grams, sodium and potassium tartrate 173 grams in 1 liter of distilled water.

The reaction is expressed by the following equation:

$$CuSO_4 + 2KOH = Cu(OH)_2 + K_2SO_4.$$

The object of the sodium and potassium tartrate is to hold the $Cu(OH)_2$ in solution. If a few cubic centimeters of this deep blue solution be boiled and dextrose then added and the solution again heated to the boiling-point, the cupric hydroxid is reduced to the condition of a cuprous oxid, which shows itself as a red or orange-yellow precipitate. The color of the precipitate depends on the relative excess of either copper or sugar, being red with the former, orange or yellow with the latter. The delicacy of this test is shown by the fact that a few minims of this solution will detect in one c.c. of water the $\frac{1}{15}$ of a milligram of sugar.

For quantitative analysis, ten c.c. of Fehling's solution, diluted with forty c.c. of water, are heated in a porcelain capsule, to which the dextrose solution is cautiously added from a buret until the blue color entirely disappears. The strength of this solution is such that one c.c. is decolorized by five milligrams of sugar, from which the percentage of sugar in any solution can be determined.

Fermentation Test.—If to a solution of dextrose a small quantity of the yeast plant be added, and the solution kept at a temperature of 25° C., it will gradually undergo fermentation; that is, will be reduced to simpler compounds and especially to alcohol and carbon dioxid. The change is expressed in the following equation:

$$\underset{\text{Dextrose.}}{C_6H_{12}O_6} = \underset{\text{Alcohol.}}{2C_2H_6O} + \underset{\substack{\text{Carbon}\\\text{Dioxid.}}}{2CO_2}.$$

About ninety-five per cent. of the dextrose is so changed, the remaining five per cent. yielding secondary products—succinic acid, glycerin, etc.

Levulose, or **fruit-sugar,** is found in association with dextrose as a constituent of many fruits. It is sweeter than dextrose and more soluble in both water and dilute alcohol. From alcoholic solutions it crystallizes in fine, silky needles, though it usually occurs in the form of a syrup.

Levulose is distinguished from dextrose by its property of turning the plane of polarized light to the left; the extent to which it does so, however, varies with the temperature and concentration of the solution.

Under the influence of the yeast plant it slowly undergoes fermentation, yielding the same products as dextrose. It also has a reducing action on cupric oxid.

Galactose is obtained by boiling milk-sugar (lactose) with dilute sulphuric acid. In many chemic relations it resembles dextrose. It is less soluble in water, however, crystallizes more easily, and has a greater dextro-rotary power. It also undergoes fermentation with the yeast plant.

3. SACCHAROSES, $C_{12}H_{22}O_{11}$.

Saccharose, or **cane-sugar,** is widely distributed throughout the vegetable world, but is especially abundant in sugar-cane, sorghum cane, sugar-beet, Indian corn, etc. It crystallizes in large monoclinic prisms. It is soluble in water and in dilute alcohol. Saccharose has no reducing power on cupric oxid, and hence its presence can not be detected by Fehling's solution. It is dextro-rotary. Boiled with dilute mineral, as well as organic acids, saccharose combines with water, and undergoes some change in virtue of which it rotates the plane of polarized light to the left, and hence the product is termed *invert* sugar. This latter has been shown to be a mixture of equal quantities of levulose and dextrose. This inversion of saccharose through hydration and decomposition is expressed by the following equation:

$$\underset{\text{Saccharose.}}{C_{12}H_{22}O_{11}} + \underset{\text{Water.}}{H_2O} = \underbrace{\underset{\text{Levulose.}}{C_6H_{12}O_6} + \underset{\text{Dextrose.}}{C_6H_{12}O_6}}_{\text{Invert Sugar.}}.$$

Saccharose is not directly fermentable by yeast, but through the specific action of a ferment, *invertin* or *invertase,* secreted by the yeast plant, or the inverting ferment of the small intestine, it undergoes inversion, as previously stated, after which it is readily fermented, yielding alcohol and carbon dioxid.

Lactose is the form of sugar found exclusively in the milk of the mammalia, from which it can be obtained in the form of hard, white, rhombic prisms united with one molecule of water. It is soluble in water, insoluble in alcohol and ether. It is dextro-rotary. It requires cupric oxid, but to a less extent than dextrose. Dilute acids decompose it into equal quantities of dextrose and galactose. Lactose is not fermentable with yeast, but in the presence of the lactic acid bacillus it is decomposed into lactic acid, and finally into butyric acid, as follows:

$$\underset{\text{Lactose.}}{C_{12}H_{22}O_{11}} + \underset{\text{Water.}}{H_2O} = \underset{\text{Lactic Acid.}}{4C_3H_6O_3}$$

$$\underset{\text{Lactic Acid.}}{2C_3H_6O_3} = \underset{\text{Butyric Acid.}}{C_4H_8O_2} + \underset{\substack{\text{Carbon}\\ \text{Dioxid.}}}{2CO_2} + \underset{\substack{\text{Free}\\ \text{Hydrogen.}}}{2H_2}$$

Maltose is a transformation product of starch, and arises whenever the latter is acted on by malt extract or the diastatic ferments in saliva and pancreatic juice. It can also be produced by the action of dilute sulphuric acid on starch. The change is expressed by the following equation:

$$\underset{\text{Starch.}}{2C_6H_{10}O_5} + \underset{\text{Water.}}{H_2O} = \underset{\text{Maltose.}}{C_{12}H_{22}O_{11}}.$$

Maltose crystallizes in the form of white needles, which are soluble in water and in dilute alcohol. It is dextro-rotary. In the presence of ferments and dilute acids maltose undergoes hydration and decomposition, giving rise to two molecules of dextrose. It has a reducing action on cupric oxid. Fermentation is readily caused by yeast, but whether directly or indirectly by inversion is somewhat uncertain.

Osazones.—All the sugars which possess the power of reducing cupric oxid are capable of combining with phenyl-hydrazin, with the formation of compounds termed osazones. The osazones so formed are crystalline in structure, but have different melting points, varying degrees of solubility and optic properties, all of which serve to detect the various sugars and to distinguish one from the other. Of the different osazones, phenyl-glucosazone is the most characteristic, and occurs in the form of long, yellow needles. It may be obtained from dextrose by the following method: To fifty c.c. of a dextrose solution add 2 gm. of phenyl-hydrazin and two gm. of sodium acetate, and boil for an hour. On cooling, the osazone crystallizes in the form of long, yellow needles.

THE FATS.

The fats constitute a group of organic bodies found in the tissues of both vegetables and animals. In the vegetable world they are largely found in fruits, seeds, and nuts, where they probably originate from a transformation of the carbohydrates. In the animal body the fats are found largely in the subcutaneous tissue, in the marrow of bones, in and around various internal organs and in milk. In these situations fat is contained in small, round or polygon-shaped vesicles, which are united by areolar tissue and surrounded by blood-vessels. At the temperature of the body the fat is liquid, but after death it soon solidifies from the loss of heat.

The fats are compounds consisting of carbon, hydrogen, and oxygen, of which the first is the chief ingredient, forming by weight about seventy-five per cent., while the last is present only in small quantity. The fat, as found in animals, is a mixture, in varying proportions in different animals, of three neutral fats—*stearin, palmitin,* and *olein.* Each fat is a derivative of glycerin and the particular acid indicated by its name—*e. g.,* stearic acid, in the case of stearin, etc. The reaction which takes place in the combination of glycerin and the acid is expressed in the following equation:

$$\underset{\text{Glycerin.}}{C_3H_5(HO)_3} + \underset{\text{Stearic Acid.}}{(HC_{18}H_{35}O_2)_3} = \underset{\text{Stearin.}}{C_3H_5(C_{18}H_{35}O_2)_3} + \underset{\text{Water.}}{3H_2O}.$$

Hence, strictly speaking, the fats are compound ethers, in which the hydrogen of the organic acid is replaced by the trivalent radicle, tritenyl, C_3H_5.

Stearin, $C_3H_5(C_{18}H_{35}O_2)_3$, is the chief constituent of the more solid fats. It is solid at ordinary temperatures, melting at 55° C., then solidifying again as the temperature rises, until at 71° C. it melts permanently. It crystallizes in square tables.

Palmitin, $C_3H_5(C_{16}H_{31}O_2)_3$, is a semifluid fat, solid at 45° C. and melting at 62° C. It crystallizes in fine needles, and is soluble in ether.

Olein, $C_3H_5(C_{18}H_{33}O_2)_3$, is a colorless, transparent fluid, liquid at ordinary temperatures, only solidifying at 0° C. It possesses marked solvent powers, and holds stearin and palmitin in solution at the temperature of the body.

Saponification.—When subjected to the action of superheated steam, a neutral fat is saponified—*i. e.*, decomposed into glycerin and the particular acid indicated by the name of the fat used: *e. g.*, stearic, palmitic, or oleic. The reaction is expressed as follows:

$$\underset{\text{Olein.}}{C_3H_5(C_{18}H_{33}O_2)_3} + \underset{\text{Water.}}{3H_2O} = \underset{\text{Glycerin.}}{C_3H_5(HO)_3} + \underset{\text{Oleic Acid.}}{3(C_{18}H_{34}O_2)}.$$

The fatty acids thus obtained are characterized by certain chemic features, as follows:

Stearic acid is a firm, white solid, fusible at 69° C. It is soluble in ether and alcohol, but not in water.

Palmitic acid occurs in the form of white, glistening scales or needles, melting at 62° C.

Oleic acid is a clear, colorless liquid, tasteless and odorless when pure. It crystallizes in white needles at 0° C.

If this saponification take place in the presence of an alkali,—*e. g.*, potassium hydroxid, sodium hydroxid,—the acid produced combines at once with the alkali to form a salt known as a soap, while the glycerin remains in solution. The reaction is as follows:

$$3KHO + (C_{18}H_{34}O_2)_3 = 3(KC_{18}H_{33}O_2) + 3H_2O.$$

Potassium. Oleic Acid. Potassium Oleate. Water

All soaps are, therefore, salts formed by the union of alkalies and fatty acids. The sodium soaps are generally hard, while the potassium soaps are soft. Those made with stearin and palmitin are harder than those made with olein. If the soap is composed of lead, zinc, copper, etc., it is insoluble in water.

Emulsification.—When a neutral oil is vigorously shaken with water or other fluid, it is broken up into minute globules that are more or less permanently suspended; the permanency depending on the nature of the liquid. The most permanent emulsions are those made with soap solutions. The process of emulsification and the part played by soap, can be readily observed by placing on a few cubic centimeters of a solution of sodium carbonate 0.25 per cent. of a small quantity of a perfectly neutral oil to which has been added 2 or 3 per cent. of a fatty acid. The combination of the acid and the alkali at once forms a soap. The energy set free by this combination rapidly divides up the oil into extremely minute globules. A spontaneous emulsion is thus formed.

In addition to the ordinary fats, there are present in different tissues several compounds which, though usually regarded as fats, nevertheless differ materially from them in composition, containing, as they do, both nitrogen and phosphorus. These nitrogenized or phosphorized fats are as follows:

Lecithin, $C_{44}H_{90}N.PO_9$, is found in blood lymph, red and white corpuscles, nerve tissue, yolk of eggs, etc. When pure, it presents itself generally under the form of a white, crystalline powder, though sometimes as a white, waxy mass. Lecithin is easily decomposed, yielding, with various reagents, glycero-phosphoric acid, cholin and stearic acid.

Protagon, $C_{160}H_{308}N_5PO_{35}$, is found most abundantly in the brain tissue, especially in the white portion. It crystallizes from warm alcoholic solutions, on cooling, in the form of white needles, generally arranged in groups. It melts at 200° C., and forms a syrupy liquid.

Cerebrin, $C_{17}H_{33}N.O_3$, is found largely in the brain, in nerves, and in pus-corpuscles. It is a soft, white, amorphous powder, insoluble in water, but swelling up like starch in boiling water. When boiled with dilute acids, it is decomposed, yielding a fermentable dextro-rotary sugar, identical with galactose. Cerebrin may, therefore, be regarded as a glucosid.

THE PROTEIDS.

The proteids constitute a group of organic bodies which are found in both vegetable and animal tissues. Though present in all animal tissues, they are especially abundant in muscles and bones, where they constitute twenty per cent. and thirty per cent. respectively. Though genetically related, and possessing many features in common, the different members of the proteid group are distinguished by characteristic physical and chemic properties.

The average percentage composition of several proteids is shown in the following analyses:

	C.	H.	N.	O.	S.	
Egg-albumin .	52.9	7.2	15.6	23.9	0.4	(Würtz).
Serum-ablumin	53.0	6.8	16.0	22.29	1.77	(Hammersten).
Casein . . .	53.3	7.07	15.91	22.03	0.82	(Chittenden and Painter).
Myosin . . .	52.82	7.11	16.77	21.90	1.27	(Chittenden and Cummins).

The molecular composition of the proteids is not definitely known, and the formulæ which have been suggested are therefore only approximative. Leow assigns to albumin the formula $C_{72}H_{112}N_{18}O_{22}S$, while Schützenberger raises the numbers to $C_{240}H_{392}N_{65}O_{75}S_3$, either of which shows that the proteid molecule is extremely complex. As a class, the proteids are characterized by the following properties:

1. **Indiffusibility.**—None of the proteids normally assumes the crystalline form, and hence they are not capable of diffusing through parchment or an animal membrane. Peptone, a product of the digestion of proteids, is an exception as regards its diffusibility. As met with in the body, all proteids are amorphous, but vary in consistence from the liquid to the solid state. The colloid character of the proteids permits of their separation and purification from crystalloid diffusible compounds by the process of dialysis.

2. **Solubility.**—Some of the proteids are soluble in water, others in solutions of the neutral salts of varying degrees of concentration, in strong acids and alkalies. All are insoluble in alcohol and ether.

3. **Coagulability.**—Under the influence of heat and various acids and animal ferments, the proteids readily pass from the soluble liquid state to the insoluble solid state, attended by a permanent alteration in their chemic composition. To this change the term coagulation has been given. The various proteids not only coagulate at different temperatures, but with different chemic reagents—distinctive features which permit not only of their detection, but separation. Proteids are capable of precipitation without losing their solubility by ammonium sulphate, sodium chlorid and magnesium sulphate.

4. **Fermentability.**—In the presence of specific microörganisms—bacteria—the proteids, owing to their complexity and instability, are prone to undergo disintegration and reduction to simpler compounds. This decomposition or putrefaction occurs most readily when the conditions most favorable to the growth of bacteria are present—viz., a temperature varying from 25° C. to 40° C., moisture and oxygen. The intermediate as well as the terminal products of the decomposition of the proteids are numerous, and vary with the composition of the proteid and the specific physiologic action of the bacteria. Among the intermediate products is a series of alkaloid bodies, some of which possess marked toxic properties, known as ptomains. The toxic symptoms which frequently follow the ingestion of foods in various stages of putrefaction are to be attributed to these compounds. The terminal products are represented by hydrogen sulphid, ammonia, carbon dioxid, fats, phosphates, nitrates, etc.

Color Tests for Proteids.—When proteids are present in solution, they may be detected by the following color reactions—viz.:

1. Xanthoproteic. The solution is boiled with nitric acid for several minutes, when the proteid assumes a light yellow color. After the solution has cooled, the addition of ammonia changes the color to an orange or amber-red.
2. The rose-red reaction. The solution is boiled with acid nitrate of mercury (Millon's reagent) for a few minutes, when the coagulated proteid turns a purple-red color.
3. The blue-violet reaction. A few drops of copper sulphate solution are first added to the proteid solution, and then an excess of sodium

hydroxid. A blue-violet color is produced, which deepens somewhat on heating, but no further change ensues.

The proteids found in the animal body, though possessing many features in common, are nevertheless characterized by certain special features which not only serve for their identification, but for their classification into well-defined groups, as follows:

SIMPLE PROTEIDS.

1. ALBUMINS.

The members of this group are soluble in water, in dilute saline solutions, and in saturated solutions of sodium chlorid and magnesium sulphate. They are coagulated by heat, and when dried form an amber-colored mass.

(*a*) **Serum-albumin** is found in blood, lymph, chyle, tissue fluids, and milk. It is obtained readily by precipitation from blood-serum, after the other proteids have been removed, on the addition of ammonium sulphate. When freed from saline constituents, it presents itself as a pale, amorphous substance, soluble in water and in strong nitric acid. It is coagulated at a temperature of 73° C., as well as by various acids—*e. g.*, citric, picric, nitric, etc. It has a rotary power of —62.6°.

(*b*) **Egg-albumin.**—Though not a constituent of the human body, egg-albumin resembles the foregoing in many respects. When obtained in the solid form from the white of the egg, it is a yellow mass without taste or odor. Though similar to serum-albumin, it differs from it in being precipitated by ether, in coagulating at 54°C., and in having a lower rotary power, —35.5°.

2. GLOBULINS.

The members of this group are insoluble in water and in saturated solutions of sodium chlorid and magnesium sulphate and ammonium sulphate. They are soluble, however, in dilute saline solutions—*e. g.*, sodium chlorid (one per cent.), potassium chlorid, ammonium chlorid, etc. They are coagulated by heat.

(*a*) **Serum-globulin** or **Paraglobulin.**—This proteid, as its name implies, is found in blood-serum, though it is present in other animal fluids. When precipitated by magnesium sulphate or carbon dioxid, it presents itself as a flocculent substance, insoluble in water, soluble in dilute acids and alkalies, and coagulating at 75° C.

(*b*) **Fibrinogen.**—This proteid is found in blood plasma in association with serum-globulin and serum-albumin. It is also present in lymph-tissue fluids and in pathologic transudates. It can be obtained from blood-plasma which has been previously treated with magnesium sulphate on the addition of a saturated solution of sodium chlorid. It is soluble in dilute acids and alkalies, and coagulates at 56° C.

(*c*) **Myosinogen.**—This proteid is a constituent of the protoplasm of the muscle-fibers. During the living condition it is liquid, but after death it readily undergoes decomposition into an insoluble portion known as myosin and a soluble albumin. It is soluble in dilute hydrochloric acid and dilute alkalies. It coagulates at 56° C.

(*d*) **Globin.**—This is a product of the spontaneous decomposition of the coloring matter of the blood,—hemoglobin,—and arises when the latter is exposed to the air.

(*e*) **Crystallin** or **Globulin.**—This is obtained by passing a stream of CO_2 through a watery extract of the crystalline lens.

3. DERIVED ALBUMINS OR ALBUMINATES.

The proteids of this group are derived from both native albumins and globulins by the gradual action of dilute acids and alkalies, and may be regarded as compounds of a proteid with an acid or an alkali.

(*a*) **Acid-albumin.**—This is formed when a native albumin is digested with dilute hydrochloric acid (0.2 per cent.) or dilute sulphuric acid for some minutes. It is precipitated by neutralization with sodium hydroxid (0.1 per cent. solution). After the precipitate is washed, it is found to be insoluble in distilled water and in neutral saline solutions. In acid solutions it is not coagulated by heat.

(*b*) **Alkali-albumin.**—This is formed when a native albumin is treated with a dilute alkali—*e. g.,* 0.1 per cent. of sodium hydroxid—for five or ten minutes. On careful neutralization with dilute hydrochloric acid, it is precipitated. It is also insoluble in distilled water and in alkaline solutions; it is not coagulable by heat.

4. COAGULATED PROTEIDS.

Although these proteids are not found as constituents of the animal organism, they possess much interest on account of their relation to prepared foods and to the digestive process. They are produced when solutions of egg-albumin, serum-albumin, or globulins are subjected to a temperature of 100° C. or to the prolonged action of alcohol. They are insoluble in water, in dilute acids, and in neutral saline solutions. In this same group may be included also those coagulated proteids which are produced by the action of animal ferments on soluble proteids—*e. g.,* fibrin, myosin, casein.

(*a*) **Fibrin.**—Fibrin is derived from a soluble proteid—fibrinogen—by the action of a special ferment. It is not present under normal circumstances in the circulating blood, but makes its appearance after the blood is withdrawn from the vessels and at the time of coagulation. It can also be obtained by whipping the blood with a bundle of twigs, on which it accumulates. When freed from blood by washing under water, it is seen to consist of bundles of white elastic fibers or threads. It is insoluble in water, in alcohol, and ether. In dilute acids it swells, becomes transparent, and finally is converted into acid-albumin. In dilute alkalies a similar change takes place, but the resulting product is an alkali-albumin. Fibrin possesses the property of decomposing hydrogen dioxid, H_2O_2—*i. e.,* liberating oxygen, which accumulates in the form of bubbles on the fibrin. On incineration fibrin yields an ash which contains calcium phosphate and magnesium phosphate.

(*b*) **Myosin.**—Myosin develops in muscles after death and is the cause of the stiffening of the muscles. It has been regarded as a derivative of the soluble proteid myosinogen alone, but there is evidence that in its formation both paramyosinogen and myosinogen take part. It is not definitely known whether this is the result of the action of a special ferment or not.

(*c*) **Casein.**—Casein is derived from the chief proteid of milk—caseinogen—by the action of a special ferment known as rennin or chymosin. This ferment is a constituent of gastric juice.

5. PROTEOSES AND PEPTONES.

During the progress of the digestive process, as it takes place in the stomach and intestines, there is produced by the action of the gastric and pancreatic juices, out of the proteids of the food, a series of new proteids, knows as proteoses and peptones. The chemic properties of these substances will be considered in connection with the process of digestion.

CONJUGATED OR COMBINED PROTEIDS.

The different members of this group are capable of being decomposed by chemic methods into a proteid and a non-proteid substance; *e. g.*, a coloring matter, a carbohydrate, or a nuclein. The chemic character of the non-proteid substance furnishes the basis for the following classification:

1. CHROMO-PROTEIDS.

(*a*) **Hemoglobin.**—Hemoglobin is the coloring matter of the red corpuscles, of which it constitutes about 94 per cent. It possesses the power of absorbing oxygen as it passes through the lung capillaries and of yielding it up to the tissues as it passes through the tissue capillaries. In the arterial blood it is known as oxyhemoglobin, and in the venous blood as dioxy- or reduced hemoglobin. When hydrolyzed by acids or alkalies, hemoglobin undergoes a cleavage into a proteid, globin, and a pigment hematin.

(*b*) **Myohematin.**—Myohematin is a proteid supposed to be present in muscle. It has never been isolated, hence its chemic features are unknown. Spectroscopic examination indicates that it is capable of absorbing and again yielding up oxygen. For this reason it is believed to be a derivative of hemoglobin.

2. GLUCO-PROTEIDS.

(*a*) **Mucin.**—Mucin is the proteid which gives the mucus secreted by the epithelial cells of the mucous membranes and related glands its viscid, tenacious character. It is also a constituent of the intercellular substances of the connective tissues. It is readily precipitated by acetic acid. When heated with dilute acids, mucin undergoes a cleavage into a similar proteid and a carbohydrate termed mucose, which is capable of reducing Fehling's solution.

(*b*) **Mucoids.**—The mucoids resemble the mucins though differing from them in solubility and in not being precipitable from alkaline solutions by acetic acid. They are found in the vitreous humor, white of egg, cartilage, and in other situations. They differ slightly one from the other in properties and chemic composition. They yield on decomposition a carbohydrate.

3. NUCLEO-PROTEIDS.

The nucleo-proteids are obtained from the nuclei and cell-substance of tissue-cells. Chemically they are characterized by the presence of phosphorus in relatively large amounts. When hydrolyzed, they separate into a proteid and a nuclein.

The nucleins derived from cell nuclei can be still further separated into a simpler proteid and *nucleic* acid, which latter in turn yields phosphoric acid and the so-called purin bases, xanthin, hypoxanthin, adenin, and guanin. All nucleins which yield the purin bases are termed *true nucleins.*

The nucleins derived from caseinogen, vitellin, and probably cell protoplasm can be separated by chemic methods into a proteid and phosphoric acid only. For the reason that they do not give origin to purin bases they are termed *pseudo-* or *paranucleins.*

(*a*) **Caseinogen.**—This is the principal proteid of milk, in which it exists in association with an alkali, and hence was formerly regarded as an alkali-albumin. It is *precipitated* by acetic acid and by magnesium sulphate. It is *coagulated* by rennet —that is, separated into an insoluble proteid, casein or tyrein, and a soluble albumin. Calcium phosphate seems to be the natural alkali necessary to this process, for if it be removed by dialysis, or precipitated by the addition of potassium oxalate, coagulation does not take place.

(*b*) **Vitellin.**—Vitellin is a constituent of the vitellis or yolk of eggs. It differs from other proteids in the fact that it is semicrystalline in character. Though usually regarded as a nucleo-proteid it is not definitely known whether or not it contains phosphorus in its composition.

ALBUMINOIDS.

The albuminoids constitute a group of substances similar to the proteids in many respects, though differing from them in others. When obtained from the tissues, in which they form an organic basis, they are found to be amorphous, colloid, and when decomposed yield products similar to those of the true proteids. The principal members of the group are as follows:

(*a*) **Collagen, Ossein.**—These are two closely allied, if not identical, substances, found respectively in the white fibrous connective tissue and in bone. When the tendons of muscles, the ligaments, or decalcified bone are boiled for several hours, the collagen and ossein are converted into soluble gelatin, which, when the solution cools, becomes solid.

(*b*) **Chondrigen.**—This is supposed to be the organic basis of the more permanent cartilages. When they are boiled, they yield a substance which gelatinizes on cooling, and to which the name chondrin has been given.

(*c*) **Elastin** is the name given to the substance composing the fibers of the yellow, elastic connective tissue.

(*d*) **Keratin** is the substance found in all horny and epidermic tissues, such as hairs, nails, scales, etc. It differs from most proteids in containing a high percentage of sulphur.

INORGANIC CONSTITUENTS.

The inorganic compounds and mineral constituents obtained from the solids and fluids of the body are very numerous, and, in some instances, quite abundant. Though many of the compounds thus obtained are undoubtedly derivatives of the tissues and necessary to their physical and physiologic activity, others, in all probability, are decomposition products, or transitory constituents introduced with the food. Of the inorganic compounds, the following are the most important:

WATER.

Water is the most important of the inorganic constituents, as it is indispensable to life. It is present in all the tissues and fluids without exception, varying from 99 per cent. in the saliva to 80 per cent.

in the blood, 75 per cent. in the muscles to 2 per cent. in the enamel of the teeth. The total quantity contained in a body weighing 75 kilograms (165 pounds) is 52.5 kilograms (115 pounds). Much of the water exists in a free condition, and forms the chief part of the fluids, giving to them their characteristic degree of fluidity. Possessing the capability of holding in solution a large number of inorganic as well as some organic compounds, and being at the same time diffusible, it renders an interchange of materials between all portions of the body possible. It aids in the absorption of new material into the blood and tissues, and at the same time it transfers waste products from the tissues to the blood, from which they are finally eliminated, along with the water in which they are dissolved. A portion of the water is chemically combined with other tissue constituents, and gives to the tissues their characteristic physical properties. The consistency, elasticity, and pliability are, to a large extent, conditioned by the amount of water they contain. The total quantity of water eliminated by the kidneys, lungs, and skin amounts to about three kilograms (6½ pounds).

CALCIUM COMPOUNDS.

Calcium phosphate, $Ca_3(PO_4)_2$, has a very extensive distribution throughout the body. It exists largely in the bones, teeth, and to a slight extent in cartilage, blood, and other tissues. Milk contains 0.27 per cent. The solidity of the bones and teeth is almost entirely due to the presence of this salt, and is, therefore, to be regarded as necessary to their structure. It enters into chemic union with the organic matter, as shown by the fact that it can not be separated from it except by chemic means, such as hydrochloric acid. Though insoluble in water, it is held in solution in the blood and milk by the proteid constituents, and in the urine by the acid phosphate of soda. The total quantity of calcium phosphate which enters into the formation of the body has been estimated at 2.5 kilograms. The amount eliminated daily from the body has been estimated at 0.4 gm., a fact which indicates that nutritive changes do not take place with much rapidity in those tissues in which it is contained.

Calcium carbonate, $CaCO_3$, is present in practically the same situations in the body as the phosphate, and plays essentially the same rôle. It is, however, found in the crystalline form, aggregated in small masses in the internal ear, forming the otoliths, or ear stones.

Though insoluble, it is held in solution by the carbonic acid diffused through the fluids.

Calcium chlorid, CaF_2, is found in bones and teeth.

SODIUM COMPOUNDS.

Sodium chlorid, $NaCl$, is present in all the tissues and fluids of the body, but especially in the blood, 0.6 per cent.; lymph, 0.5, and pancreatic juice, 0.25 per cent. The entire quantity in the body has been estimated at about 200 gm. Sodium chlorid is of much importance in the body, as it determines and regulates to a large extent the phenomena of diffusion which are there constantly taking place. This is illustrated by the fact that a solution of albumin placed in the rectum without the addition of this salt will not be absorbed. When the salt is added, absorption takes place. The ingested water is absorbed into the blood largely in consequence of the percentage of this salt which it contains. The normal percentage of sodium chlorid in the blood-plasma assists in maintaining the shape and structure of the red blood-corpuscles by determining the amount of water entering into their composition. The same is true of other tissue elements.

Sodium chlorid also influences the general nutritive process, increasing the disintegration of the proteids, as shown by the increased amount of urea excreted. During its existence in the body it undergoes some chemic transformations or decompositions, yielding its chlorid to form potassium chlorid of the blood-corpuscles and muscles and to form the hydrochloric acid of the gastric juice.

Sodium phosphate, Na_2HPO_4, is found in all solids and fluids of the body, to which, with but few exceptions, it imparts an alkaline reaction. This is especially true of blood, lymph, and tissue fluids generally. It is essential to physiologic action that all tissue elements should be bathed by an alkaline medium.

Sodium carbonate, Na_2CO_3, is generally found in association with the preceding salt. As it is also an alkaline compound, it assists in giving to the blood and lymph their characteristic alkalinity. In carnivorous animals the sodium phosphate is the more abundant, while in the herbivorous animals the reverse is true.

Sodium sulphate, Na_2SO_4, is present in many of the tissues and fluids, especially the urine. Though introduced in the food, it is also, in all probability, formed in the body from the decomposition and oxidation of the proteids.

POTASSIUM COMPOUNDS.

Potassium chlorid, KCl, is met with in association with sodium chlorid in almost all situations in the body. It preponderates, however, in the tissue elements, especially in the muscle tissue, nerve tissue, and red corpuscles. The plasma with which these structures are bathed contains but a very small amount of this salt, but, as previously stated, a relatively large quantity of sodium chlorid. Though introduced to some extent in the food, it is very likely that it is also formed through the decomposition of the sodium chlorid.

Potassium phosphate, K_2HPO_4, is found in association with sodium phosphate in all the fluids and solids. As it has similar chemic properties, its functions are practically the same.

Potassium carbonate, K_2CO_3, is generally found with the preceding salt.

MAGNESIUM COMPOUNDS.

Magnesium phosphate, $Mg_3(PO_4)_2$, is found in all tissues, in association with calcium phosphate, though in much smaller quantity.

Magnesium carbonate, $MgCO_3$, occurs only in traces in the blood. Both of these compounds have functions similar to the calcium compounds, and exist, in all probability, under similar conditions.

IRON COMPOUNDS.

Iron is a constituent of the coloring matter of the blood. Traces, however, are also found in lymph, bile, gastric juice, and in the pigment of the eyes, skin, and hair. The amount of iron contained in a body weighing seventy-five kilograms is about three gm. It exists under various forms—*e. g.,* ferric oxid, ferrous oxid, and in combination with organic compounds.

Chemic analysis thus shows that the chemic elements into which the compounds may be resolved by an ultimate analysis do not exist in the body in a free state, but only in combination, and in characteristic proportions, to form compounds whose properties are the resultant of those of the elements. Of the four principal elements which make up ninety-seven per cent. of the body, O, H, N are extremely mobile, elastic, and possessed of great atomic heat. C, H, N are distinguished for the narrow range of their affinities, and for their chemic inertia. C possesses the great atomic cohesion. O is noted for the number and intensity of its combinations.

As the properties of the compounds formed by the union of elements must be the resultants of the properties of the elements themselves, it follows that the ternary compounds, starches, sugars, and fats must possess more or less inertia, and at the same time instability; while in the more complex proteids, in which sulphur and phosphorus are frequently combined with the four principal elements, molecular instability attains its maximum. As all the foregoing compounds possess in varying degrees the properties of inertia and instability, it follows that living matter must possess corresponding properties, and the capability of undergoing unceasingly a series of chemic changes, both of composition and decomposition, in response to the chemic and physical influences by which it is surrounded, and which underlie all the phenomena of life.

PRINCIPLES OF DISSIMILATION.

In addition to the previously mentioned compounds,—viz., carbohydrates, fats, proteids, and inorganic salts,—there is obtained by chemic analysis from the tissues and fluids of the body:

1. A number of organic acids, such as acetic, lactic, oxalic, butyric, propionic, etc., in combination with alkaline and earthy bases.
2. Organic compounds, such as alcohol, glycerin, cholesterin.
3. Pigments, such as those found in bile and urine.
4. Crystallizable nitrogenized bodies, such as urea, uric acid, xanthin, hippuric acid, creatin, creatinin, etc.

While some few of these compounds may possibly be regarded as necessary to the physiologic integrity of the tissues and fluids, the majority of them are to be regarded as products of dissimilation of the tissues and foods in consequence of functional activity, and represent stages in their reduction to simpler forms previous to being eliminated from the body.

PHYSIOLOGY OF THE CELL.

A microscopic analysis of the tissues shows that they can be resolved into simpler elements, termed cells, which may, therefore, be regarded as the primary units of structure. Though cells vary considerably in shape, size, and chemic composition in the different tissues of the adult body, they are, nevertheless, descendants from typical cells, known as embryonic or undifferentiated cells, examples of which are the leukocytes of the blood and lymph and the first offspring of the fertilized ovum. Ascending the line of embryonic development, it will be found that every organized body originates in a single cell—the ovum. As the cell is the elementary unit of all tissues, the function of each tissue must be referred to the function of the cell. Hence the cell may be defined as the primary anatomic and physiologic unit of the organic world, to which every exhibition of life, whether normal or abnormal, is to be referred.

Structure of Cells.—Though cells vary in shape and size and intrenal structure in different portions of the body, a typical cell may be said to consist mainly of a gelatinous substance forming the body of the cell, termed *protoplasm* or *bioplasm*, in which is embedded a smaller spheric body, the *nucleus*. The shape of the adult cell varies according to the tissue in which it is found; when young and free to move in a fluid medium, the cell assumes a spheric form, but when subjected to pressure, may become cylindric, fusiform, polygonal, or stellate. Cells vary in size within wide limits, ranging from $\frac{1}{3200}$ of an inch, the diameter of a red blood-corpuscle, to $\frac{1}{200}$ of an inch, the diameter of the large cells in the gray matter of the spinal cord. (See Fig. 2.)

The **cell protoplasm** consists of a soft, semifluid, gelatinous material, varying somewhat in appearance in different tissues. Though frequently homogeneous, it often exhibits a finely granular appearance under medium powers of the microscope. Young cells consist almost entirely of clear protoplasm, mature cells contain, according to the tissue in which they are found, material of an entirely different character—*e. g.,* small globules of fat, granules of glycogen, mucigen, pigments, digestive ferments, etc. Under high powers of the microscope the cell protoplasm is found to be pervaded by a network of fibers, termed *spongioplasm,* in the meshes of which is contained a clearer and more fluent substance, the *hyaloplasm.* The relative amount of these two constituents varies in different cells, the proportion of hyaloplasm being usually greater in young cells. The arrangement of the fibers forming the spongioplasm also varies, the fibers having sometimes a radial direction, in others a concentric disposition, but most frequently being distributed evenly in all directions. In many cells the outer portion of the cell protoplasm undergoes chemic changes and is transformed into a thin, transparent, homogeneous membrane,—the cell membrane,—which completely incloses the cell substance. The cell membrane is permeable to water and watery solutions of various inorganic and organic substances. It is, however, not an essential part of the cell.

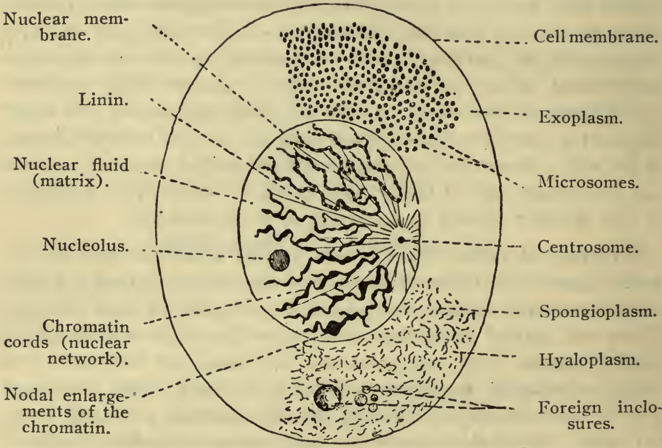

Nuclear membrane.
Linin.
Nuclear fluid (matrix).
Nucleolus.
Chromatin cords (nuclear network).
Nodal enlargements of the chromatin.
Cell membrane.
Exoplasm.
Microsomes.
Centrosome.
Spongioplasm.
Hyaloplasm.
Foreign inclosures.

FIG. 2.—DIAGRAM OF A CELL.

Microsomes and spongioplasm are only partly drawn.

The **nucleus** is a small vesicular body embedded in the protoplasm near the center of the cell. In the resting condition of the cell it consists of a distinct membrane, composed of *amphipyrenin,* inclosing the nuclear contents. The latter consists of a homogeneous amorphous substance,—the nuclear matrix,—in which is embedded the nuclear network. It can often be seen that a portion of one side of the nucleus, called the pole, is free from this network. The main cords of the network are arranged as V-shaped loops about it. These main cords send out secondary branches or twigs, which, uniting with one another, complete the network. The nuclear cords are composed of granules of *chromatin*,—so called because of its affinity for certain staining materials,—held together by an achromatin substance known as *linin*. Besides the nuclear network, there are embedded in the nuclear matrix one or more small bodies composed of *pyrenin*, known as nucleoli. At the pole of the nucleus, either within or just without in the protoplasm, is a small body, the *centrosome*, or pole corpuscle.

Chemic Composition of the Cell.—The composition of living protoplasm is difficult of determination, for the reason that all chemic and physical methods employed for its analysis destroy its vitality, and the products obtained are peculiar to dead rather than to living matter. Moreover, as protoplasm is the seat of constructive and destructive processes, it is not easy to determine whether the products of analysis are crude food constituents or cleavage or disintegration products. Nevertheless, chemic investigations have shown that even in the living condition protoplasm is a highly complex compound—the resultant of the intimate union of many different substances. About seventy-five per cent. of protoplasm consists of water and twenty-five per cent. of solids, of which the more important compounds are various nucleo-proteids (characterized by their large percentage of phosphorus), globulins, traces of lecithin, cholesterin, and frequently fat and carbohydrates. Inorganic salts, especially the potassium, sodium, and calcium chlorids and phosphates, are almost invariable and essential constituents.

MANIFESTATIONS OF CELL LIFE.

Growth, Nutrition.—All cells exhibit the three fundamental properties of life—viz., growth, nutrition, reproduction. All cells when newly reproduced are extremely small, but by the absorption of nutritive material from their surrounding medium, they gradually grow until they attain their mature size. This is accomplished by the power which living material possesses of transforming, vitalizing, and organizing crude nutritive material, through a series of upward changes, into material similar to itself. To all these changes the term *assimilation*, or *anabolism*, has been given. Some of the absorbed material, in all probability, never becomes an integral part of the living bioplasm, but undergoes disruption and oxidation, giving rise at once to heat and force. Coincident with the assimilative processes, a series of disintegrative processes is constantly taking place, whereby the living material is reduced, through a series of downward chemic changes, to simpler compounds, such as water, carbon dioxid, urea, etc. To all these downward changes the term *dissimilation,* or *katabolism,* has been given. As a result, also, of these various changes, the protoplasm gives rise to the production of material of an entirely different character, such as globules of fat, granules of glycogen, mucigen, digestive ferments, etc. The sum total of all changes which go on in the cell, both assimilative and dissimilative, are embraced under the general term nutrition, or *metabolism.* Every cell presents in its nutritive activities an epitome of the nutritive activities of the body as a whole.

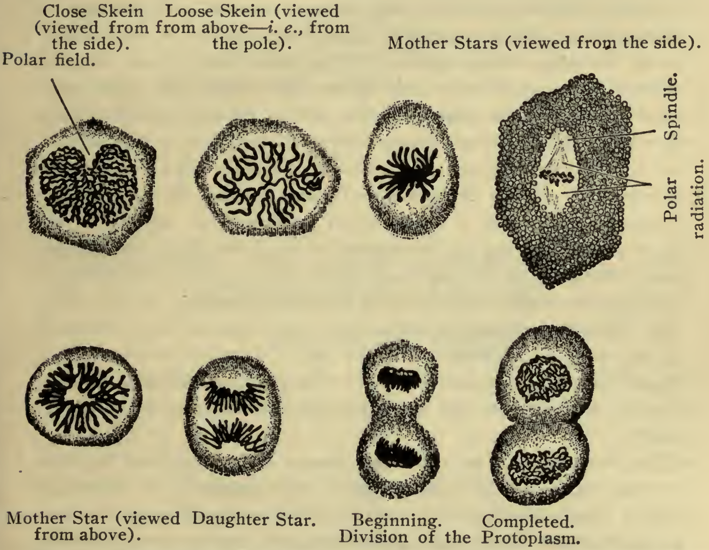
Physiologic Properties of Protoplasm.—All living protoplasm possesses properties which serve to distinguish and characterize it—viz., irritability, conductivity, and motility.

Irritability, or the power of reacting in a definite manner to some form of external excitation, whether mechanical, chemic, or electric, is a fundamental property of all living protoplasm. The character and extent of the reaction will vary, and will depend both on the nature of the protoplasm and the character and strength of the stimulus. If the protoplasm be muscle, the response will be a contraction; if it be gland, the response will be secretion; if it be nerve, the response will be a sensation or some other form of nerve activity.

Conductivity, or the power of transmitting molecular disturbances arising at one point to all portions of the irritable material, is also a characteristic feature of all protoplasm. This power, however is best developed in that form of protoplasm found in nerves, which serves to transmit, with extreme rapidity, molecular disturbances arising at the periphery to the brain, as well as in the reverse direction. Muscle protoplasm also possesses the same power in a high degree.

Motility, or the power of executing apparently spontaneous movements, is exhibited by many forms of cell protoplasm. In addition to the molecular movements which take place in certain cells, other forms of movement are exhibited, more or less constantly, by many cells in the animal body—*e. g.,* the waving of cilia, the ameboid movements and migrations of white blood corpuscles, the activities of spermatozooids, the projections of pseudopodia, etc. These movements, arising without any recognizable cause, are frequently spoken of as spontaneous. Strictly speaking, however, all protoplasmic movement is the resultant of natural causes, the true nature of which is beyond the reach of present methods of investigation.

Reproduction.—Cells reproduce themselves in the higher animals in two ways—by direct division and by indirect division, or karyokinesis. In the former the nucleus becomes constricted, and divides without any special grouping of the nuclear elements. It is probable that this occurs only in disintegrating cells, and never in a physiologic multiplication. In division by karyokinesis (Fig. 3) there is a progressive rearranging and definite grouping of the nucleus, the result of which changes is the division of the centrosome, the



Close Skein (viewed from the side). Loose Skein (viewed from above—*i. e.*, from the pole). Mother Stars (viewed from the side).

Mother Star (viewed from above). Daughter Star. Beginning. Completed. Division of the Protoplasm.

FIG. 3.—KARYOKINETIC FIGURES OBSERVED IN THE EPITHELIUM OF THE ORAL CAVITY OF A SALAMANDER.

The picture in the upper right-hand corner is from a section through a dividing egg of Siredon pisciformis. Neither the centrosomes nor the first stages of the development of the spindle can be seen by this magnification. × 560.

chromatin, and the rest of the nucleus into two equal portions, which form the nuclei. Following the division of the nuclei, the protoplasm divides. The process may be divided into three phases:

1. Prophase.—The centrosome, at first small and lying within the nucleus, increases in size and moves into the protoplasm, where it lies near the nucleus, surrounded by a clear zone, from which delicate threads radiate through an area known as the *attraction sphere.* The nucleus enlarges and becomes richer in chromatin. The lateral twigs of the chromatin cords are drawn in, while the main cords become much contorted. These cords have a general direction transverse to the long axis of the cell, and parallel to the plane of future cleavage. They are seen as V-shaped segments or loops, *chromosomes,* having their closed ends directed toward a common center, the *polar field,* while the other ends interdigitate on the opposite side of the nucleus—the anti-pole. The polar field corresponds to the area occupied by the centrosome. This arrangement is known as the *close skein;* but as the process goes on, the chromosomes become thicker, shorter and less contorted, producing a much looser arrangement, known as the *loose skein.* During the formation of the loose skein, the centrosome divides into two portions, which move apart to positions at the opposite ends of the long axis of the nucleus. At the same time delicate achromatin fibers make their appearance, arranged in the form of a double cone, the apices of which correspond in position to the centrosome. This is known as the *nuclear spindle.* During the prophase the nuclear membrane and the nucleoli disappear.
2. The Metaphase.—The two centrosomes are at opposite ends of the long axis of the nucleus, each surrounded by an attraction sphere, now called the *polar radiation.* The chromosomes become yet shorter and thicker, and move toward the equator of the nucleus, where they lie with their closed ends toward the axis, presenting the appearance, when seen from the poles, of a star,—the so-called mother star, or monaster. While moving toward the equator of the nucleus, and often earlier, each chromosome undergoes longitudinal cleavage, the sister loops remaining together for a time. Upon the completion of the monaster, one loop of each pair passes to each pole of the nucleus, guided, and perhaps drawn by the threads of the nuclear spindle. The separation of the sister segments begins at their apices, and as the open ends are drawn

apart they remain connected by delicate achromatin filaments drawn out from the chromosomes. This separation of the daughter chromosomes, and their movement toward the daughter centrosomes, is called *metakinesis*. As they approach their destination, we have the appearance of two stars in the nucleus—the *daughter stars,* or diasters.

3. Anaphase.—The daughter stars undergo, in reverse order, much the same changes that the mother star passed through. The chromosomes become much convoluted, and perhaps united to one another, the lateral twigs appear, and the chromatin resumes the appearance of the resting nucleus. The nuclear spindle, with most of the polar radiation, disappears, and the nucleoli and the nuclear membrane reappear, thus forming two complete daughter nuclei. Meanwhile the protoplasm becomes constricted midway between the young nuclei. This constriction gradually deepens until the original cell is divided, with the formation of two complete cells.

HISTOLOGY OF THE EPITHELIAL AND CONNECTIVE TISSUES.

1. EPITHELIAL TISSUE.

The **epithelial tissue** consists of one or more layers of cells resting on a homogeneous membrane, the other side of which is abundantly supplied with blood-vessels and nerves. The form of the epithelial cell varies in different situations, and may be flattened, cuboid, spheroid, or columnar. The form of the cell in all instances is related to some specific function. When arranged in layers or strata, the cells are cemented together by an intercellular substance—mucin.

The epithelial tissue forms a continuous covering for the surfaces of the body. The external investment (the skin) and the internal investment (the mucous membrane, which lines the entire alimentary canal and its associated body cavities) are both formed, in all situations, by the homogeneous basement membrane, covered with one or more layers of cells. All materials, therefore, whether nutritive, secretory, or excretory, must pass through epithelial cells before they can enter into the formation of the blood or be eliminated from it. The nutrition of the epithelial tissue is maintained by the nutritive material derived from the blood diffusing itself into and through the basement membrane. Chemically, the epithelial cells of the epidermis—hair, nails, etc.—are composed of an albuminoid material (keratin), a small quantity of water, and inorganic salts. In other situations, especially on the mucous membranes, the cells consist largely of mucin, in association with other proteids. The consistency of epithelium varies in accordance with external influences, such as the presence or absence of moisture, pressure, friction, etc. This is well seen in the skin of the palms of the hands and the soles of the feet—situations where it acquires its greatest density. In the alimentary canal, in the lungs, and in other cavities, where the reverse conditions prevail, the epithelium is extremely soft. Epithelial tissues also possess varying degrees of cohesion and elasticity—physical properties which enable them to resist considerable pressure and distension without having their physiologic integrity destroyed. Inasmuch as these tissues are poor conductors of heat, they assist in preventing too rapid radiation of heat from the body, and coöperate with other mechanisms in maintaining the normal temperature. The physiologic activity of all epithelial tissue depends on a due supply of nutritive material derived from the blood, which not only maintains its own nutrition, but affords those materials out of which are formed the secretions of the glands, whether of the skin or mucous membrane.

Functions of Epithelial Tissue.—In succeeding chapters the form, chemic composition, and functions of epithelial cells will be considered in connection with the functions of the organs of which they constitute a part. In this connection it may be stated in a general way that the functions of the epithelial tissues are:

1. To serve on the surface of the body as a protective covering to the underlying structures which collectively form the true skin, thus protecting them from the injurious influences of moisture, air, dust, microörganisms, etc., which would otherwise impair their vitality. Wherever continuous pressure is applied to the skin, as on the palms of the hands and soles of the feet, the epithelium increases in thickness and density, and thus prevents undue pressure on the nerves of the true skin. The density of the epidermis enables it to resist, within limits, the injurious influences of acids, alkalies, and poisons,

2. To promote absorption. Inasmuch as the skin and mucous membranes cover the surfaces of the body, it is obvious that all nutritive material entering the body must first traverse the epithelial tissue. Owing to their density, however, the epithelial cells covering the skin play but a feeble rôle as absorbing agents in man and the higher animals. The epithelium of the mucous membrane of the alimentary canal, particularly that of the small intestine, is especially adapted, from its situation, consistency, and properties, to play the chief rôle in the absorption of new materials into the blood. The epithelium lining the air-vesicles of the lungs is engaged in promoting the absorption of oxygen and the exhalation of carbon dioxid.
3. To form secretions and excretions. Each secretory gland connected with the surfaces of the body is lined by epithelial cells, which are actively concerned in the formation of the secretion peculiar to the gland. Each excretory organ is similarly provided with epithelial cells, which are engaged either in the production of the constituents of the excretion or in their removal from the blood.

2. THE CONNECTIVE TISSUES.

The **connective tissues,** in their collective capacity, constitute a framework which pervades the body in all directions, and, as the name implies, serve as a bond of connection between the individual parts, at the same time affording a basis of support for the muscle, nerve, and gland tissues. The connective-tissue group includes a number of varieties, among which may be mentioned the areolar, adipose, retiform, white fibrous, yellow elastic, cartilaginous and osseous. Notwithstanding their apparent diversity, they possess many points of similarity. They have a common origin, developing from the same embryonic material; they have much the same structure, passing imperceptibly into one another, and perform practically the same functions.

Areolar Tissue.—This variety is found widely distributed throughout the body. It serves to unite the skin and mucous membrane to the structures on which they rest; to form sheaths for the support of blood-vessels, nerves, and lymphatics; to unite into compact masses the muscular tissue of the body, etc. Examined with the naked eye, it presents the appearance of being composed of bundles of fine fibers interlacing in every direction. In the embryonic state the elements of this form of connective tissue are united by a ground substance, gelatinous in character. In the adult state this substance shrinks and largely disappears, leaving intercommunicating spaces of varying size and shape, from which the tissue takes its name. When subjected to the action of various reagents, and examined microscopically, the bundles can be shown to consist of extremely delicate, colorless, transparent, wavy fibers, which are cemented together by a ground substance composed largely of mucin. Other fibers are also observed, which are distinguished by a straight course, a sharp, well-defined outline, a tendency to branch and unite with adjoining fibers, and to curl up at their extremities when torn. From their color and elasticity they are known as yellow elastic fibers. Distributed throughout the meshes of the areolar tissue are found flattened, irregularly branched, or stellate corpuscles, connective-tissue corpuscles, plasma cells, and granule cells.

Adipose Tissue.—This tissue, which exists very generally throughout the body, though found most abundantly beneath the skin, around the kidneys, and in the bones, is practically but a modification of areolar tissue. In these situations it presents itself in small masses or lobules of varying size and shape, surrounded and penetrated by the fibers of connective tissue. Microscopic examination shows that these masses consist of small vesicles or cells, round, oval, or polyhedral in shape, depending somewhat on pressure. Each vesicle consists of a thin, colorless, protoplasmic membrane, thickened at one point, in which a nucleus can usually be detected. This membrane incloses a globule of fat, which during life is in the liquid state. It is composed of olein, stearin, and palmitin. The origin of the fat is to be referred to a retrograde change in the protoplasmic material of the connective-tissue cells. When this protoplasm becomes rich in carbon and hydrogen, it is speedily converted into fat, which makes its appearance in the form of minute drops in different portions of the cell. As the drops accumulate, at the expense of the cell protoplasm they gradually coalesce, until there remains but a thin stratum of the protoplasm, which forms the wall of the vesicle. Adipose tissue may, therefore, be regarded as areolar tissue, in which and at the expense of some of its elements, fat is stored for the future needs of the organism. A diminution of food, especially of fat and carbohydrates, is promptly followed by an absorption of fat by the blood-vessels and by its transference to the tissues, where it is either utilized for tissue construction or for oxidation purposes. In the situations in which adipose tissue is found it seems, by its chemic and physical properties, to assist in the prevention of a too rapid radiation of heat from the body, to give form and roundness, and to diminish angularities, etc.

Retiform and **adenoid tissue** are also modifications of areolar tissue. The meshes of the former contain but little ground substance, its place being taken by fluids; the meshes of the latter contain large numbers of lymph corpuscles.

Fibrous Tissue.—This variety of connective tissue is widely distributed throughout the body. It constitutes almost entirely the ligaments around the joints, the tendons of the muscles, the membranes covering organs such as the heart, liver, nervous system, bones, etc. All fibrous tissue, wherever found, can be resolved into elementary bundles, which on microscopic examination are seen to consist of delicate, wavy, transparent, homogeneous fibers, which pursue an independent course, neither branching nor uniting with adjoining fibers. A small amount of ground substance serves to hold them together. Fibrous tissue is tough and inextensible, and in consequence is admirably adapted to fulfil various mechanical functions in the body. It is, however, quite pliant, bending easily in all directions. When boiled, fibrous tissue yields gelatin, a derivative of collagen.

Elastic Tissue.—The fibers of elastic tissue are usually associated in varying proportions with the white fibrous tissue; but in some structures—as the ligamentum nuchæ, the ligamenta subflava, the middle coat of the larger blood-vessels—the elastic fibers are almost the only elements present, and give to these structures a distinctly yellow appearance. The fibers throughout their course give off many branches, which unite with adjoining branches to form a more or less close network. As the name implies, these fibers are highly elastic, and are capable of being extended as much as sixty per cent. before breaking.

Cartilaginous Tissue.—This form of connective tissue differs from the preceding varieties chiefly in its density. As a rule, it is firm in consistency, though somewhat elastic. It is opaque, bluish-white in color, though in thin sections translucent. All cartilaginous tissues consist of connective-tissue cells embedded in a solid ground substance.

According to the amount and texture of the ground substance, three principal varieties may be distinguished:

1. *Hyaline cartilage,* in which the cells, relatively few in number, are embedded in an abundant quantity of ground substance. The body of the cells is in many instances distinctly marked off from the surrounding substance by concentric lines or fibers, which form a capsule for the cell. Repeated division of the cell substance takes place, until the whole capsule is completely occupied by daughter cells. The ground substance is pervaded by minute channels, which communicate on one hand with the spaces around the cells, and on the other with lymph-spaces in the connective tissue surrounding the cartilage. By means of these channels, nutritive fluid can permeate the entire structure. Hyaline cartilage is found on the ends of the long bones, where it enters into the formation of the joints; between the ribs and sternum, forming the costal cartilage, as well as in the nose and larynx.
2. *White fibro-cartilage,* the ground substance of which is pervaded by white fibers, arranged in bundles or layers, between which are scattered the usual encapsulated cells. White fibro-cartilage is tough, resistant, but flexible, and is found in joints where strength and fixedness are required. Hence it is present between the vertebræ, forming the intervertebral discs, between the condyle of the lower jaw and the glenoid fossa, in the knee-joint, around the margins of the joint cavities, etc. In these situations it assists in maintaining the apposition of the bones, in giving a certain degree of mobility to the joints, and in diminishing the effects of shock and pressure imparted to the bones.
3. *Yellow fibro-cartilage,* the ground substance of which is pervaded by opaque, yellow elastic fibers, which form, by the interlacing of their branches, a complicated network, in the meshes of which are to be found the usual corpuscles. As these fibers are elastic, they impart to the cartilage a very considerable degree of elasticity. Yellow fibro-cartilage is well adapted, therefore, for entering into the formation of the external ear, epiglottis, Eustachian tube, etc. —structures which require for their functional activity a certain degree of flexibility and elasticity.

Osseous Tissue.—Osseous tissue, as distinguished from bone, is a member of the connective-tissue group, the ground substance of which is permeated with insoluble lime salts, of which the phosphate and carbonate are the most abundant. Immersed in dilute solutions of hydrochloric acid, they can be converted into soluble salts and dissolved out. The osseous matrix left behind is soft and pliable. When boiled, it yields gelatin.

A thin, transverse section of a decalcified bone, when examined microscopically, reveals a number of small, round or oval openings, which represent transverse sections of canals which run through the bone, for the most part in a longitudinal direction, though frequently anastomosing with one another. These so-called Haversian canals in the living state contain blood-vessels and lymphatics.

Around each Haversian canal is a series of concentric laminæ, composed of white fibers. Between every two laminæ are found small cavities (lacunæ), from which radiate in all directions small canals (canaliculi), which communicate freely with one another. The Haversian canals, with their associated lacunæ and canaliculi, form a system of intercommunicating passages, through which lymph circulates destined for the nourishment of bone. Each lacuna contains the bone corpuscle, which bears a close resemblance to the usual branched connective-tissue corpuscle, and whose function appears to be the maintenance of the nutrition of the bone.

The surface of every bone in the recent state is invested with a fibrous membrane, the periosteum, except where it is covered with cartilage. The inner surface of this membrane is loose in texture, and supports a fine plexus of capillary blood-vessels and numerous protoplasmic cells—the osteoblasts. As this layer is directly concerned in the formation of bone, it is spoken of as the *osteogenetic* layer.

A section of a bone shows that it is composed of two kinds of tissue—compact and cancellated. The compact is dense, resembling ivory, and is found on the outer portion of the bone; the cancellated is spongy, and appears to be made up of thin, bony plates, which intersect one another in all directions, and is found in greatest abundance in the interior of the bones. The shaft of a long bone is hollow. This central cavity, which extends from one end of the bone to the other, as well as the interstices of the cancellated tissue, is filled in the living state with marrow. The marrow or medulla is composed of a connective-tissue framework supporting blood-vessels. In its meshes are to be found characteristic bone cells or osteoblasts, the function of which is supposed to be the formation of bone. In the long bones the marrow is yellow, from the presence in the connective-tissue corpuscle of fat globules, which arise through the transformation of the cell protoplasm. In the cancellated tissue, near the extremities of the long bones, this fatty transformation does not take place to the same extent, and the marrow appears red. The cells of the red marrow are believed to give birth indirectly to the red blood-corpuscles.

Physical and Physiologic Properties of Connective Tissues.—Among the physical properties may be mentioned consistency, cohesion, and elasticity. Their *consistency* varies from the semiliquid to the solid state, and depends on the quantity of water which enters into their composition. Their *cohesion,* except in the softer varieties, is very considerable, and offers great resistance to traction, pressure, torsion, etc. In all the movements of the body, in the contraction of muscles, in the performance of work, the consistence and cohesion of these tissues play most important rôles. Wherever the various forms of connective tissue are found, their chemic composition and structure are in relation to their functions. If traction be the preponderating force, the structure becomes fibrous, as in ligaments and tendons, and the cohesion greatest in the longitudinal direction. If pressure be exerted in all directions, as upon membranes, the fibers interlace and offer a uniform resistance. When pressure is exerted in a definite direction, as on the extremities of the long bones, the tissue becomes expanded and cancellated. The lamellæ of the cancellated tissue arrange themselves in curves which correspond to the direction of the greatest pressure or traction. Extensibility is not a characteristic feature, except in those forms containing an abundance of yellow elastic fibers. The elasticity is an essential factor in many physiologic actions. It not only opposes and limits forces of traction, pressure, torsion, etc., but on their cessation returns the tissues or organs to their original condition. Elasticity thus assists in maintaining the natural form and position of the organs by counterbalancing and opposing temporarily acting forces.

The Skeleton.—The connective tissues in their entirety constitute a framework which presents itself under two aspects: (1) As a solid, bony skeleton, situated in the trunk and limbs, affording attachment for muscles and viscera; (2) as a fine, fibrous skeleton, found everywhere throughout the body, connecting the various viscera and affording support for the epithelial, muscle, and nerve tissues.

THE PHYSIOLOGY OF THE SKELETON.

The animal body is characterized by the power of executing a great variety of movements, all of which have reference to a change of relation of one part of the body to another, or to a change of position of the individual in space, as in the various acts of locomotion. If in the execution of these movements the different parts are applied or directed to the overcoming of opposing forces in the environment, the animal is said to be doing work. In the conception of the animal body as a machine for the accomplishment of work the skeleton, the muscle and nerve tissues constitute the three primary mechanisms, all of which bear certain definite relations one to another.

The Skeleton is the passive framework, the axial portion of which (the vertebral column, head, ribs, and sternum) impart more or less fixity and rigidity, while the appendicular portions (the bones of the arms and legs) impart extreme mobility. The bones of the arms and legs more especially may be looked upon as constituting a system of levers, the fulcra of which, the points of rest around which they move, lie in the joints.

That a lever may be effective as an instrument for the accomplishment of work, it must not only be capable of moving around its fulcrum, but it must at the same time be acted on by two opposing forces, one passive, the other active. In the movement of the bony levers of the animal body, the *passive* forces are largely those connected with the environment, *e. g.*, gravity, cohesion, friction, elasticity, etc. The *active* forces by which these latter are opposed and overcome through the intermediation of the bony levers are found in the muscles attached to them. For the execution of all these movements, it is essential that the relation of the various portions of the bony skeleton to one another shall be such as to permit of movement while yet retaining close apposition. This is accomplished by the mechanical conditions which have been evolved at the points of union of bones, and which are technically known as articulations or joints.

A consideration of the body movements involves an account of (1) the static conditions, or those states of equilibrium in which the body is at rest—*e. g.*, standing, sitting; (2) the dynamic conditions, or those states of activity characterized by movement—*e. g.*, walking, running, etc. In this connection, however, only those physical and physiologic peculiarities of the skeleton, especially in its relation to joints, will be referred to which underlie and determine both the static and dynamic states of the body.

Structure of Joints.—The structures entering into the formation of joints are:

1. *Bones,* the articulating surfaces of which are often more or less expanded, especially in the case of long bones, and at the same time variously modified and adapted to one another in accordance with the character and extent of the movements which there take place.
2. *Hyaline cartilage,* which is closely applied to the articulating end of each bone. The smoothness of this form of cartilage facilitates the movements of the opposing surfaces, while its elasticity diminishes the force of shocks and jars imparted to the bones during various muscular acts. In a number of joints, plates or discs of white fibro-cartilage are inserted between the surfaces of the bones.
3. *A synovial membrane,* which is attached to the edge of the hyaline cartilage entirely inclosing the cavity of the joint. This membrane is composed largely of connective tissue, the inner surface of which is lined by endothelial cells, which secrete a clear, colorless, viscid fluid—the synovia. This fluid not only fills up the joint-cavity, but, flowing over the articulating surfaces, diminishes or prevents friction.
4. *Ligaments,*—tough, inelastic bands, composed of white fibrous tissue,—which pass from bone to bone in various directions on the different aspects of the joint. As white fibrous tissue is inextensible but pliant, ligaments assist in keeping the bones in apposition, and prevent displacement while yet permitting of free and easy movements.

Classification of Joints.—All joints may be divided, according to the extent and kind of movements permitted by them, into (1) diarthroses; (2) amphiarthroses; (3) synarthroses.

1. *Diarthroses.*—In this division of the joints are included all those which permit of free movement. In the majority of instances the articulating surfaces are mutually adapted to each other. If the articulating surface of one bone is convex, the opposing but corresponding surface is concave. Each surface, therefore, represents a section of a sphere or a cylinder, which latter arises by rotation of a line around an axis in space. According to the number of

axes around which the movements take place all diarthrodial joints may be divided into:

1. Uniaxial Joints.—In this group the convex articulating surface is a segment of a cylinder or cone, to which the opposing surface more or less completely corresponds. In such a joint the single axis of rotation, though, practically is not exactly at right angles to the long axis of the bone, and hence the movements—flexion and extension—which take place are not confined to one plane. Joints of this character—*e. g.,* the elbow, knee, ankle, the phalangeal joints of the fingers and toes—are, therefore, termed ginglymi, or hinge-joints. Owing to the obliquity of their articulating surfaces, the elbow and ankle are *cochleoid* or *screw-ginglymi.* Inasmuch as the axes of these joints on the opposite sides of the body are not coincident, the right elbow and left ankle are right-handed screws; the left elbow and right ankle, left-handed screws. In the knee-joint the form and arrangement of the articulating surfaces are such as to produce that modification of a simple hinge known as a *spiral hinge,* or *helicoid.* As the articulating surfaces of the condyles of the femur increase in convexity from before backward, and as the inner condyle is longer than the outer, and therefore, represents a spiral surface, the line of translation or the movement of the leg is also a spiral movement. During flexion of the leg there is a simultaneous inward rotation around a vertical axis passing through the outer condyle of the femur; during extension a reverse movement takes place. Moreover, the slightly concave articulating surfaces of the tibia do not revolve around a single fixed transverse axis, as in the elbow-joint, for during flexion they slide backward, during extension forward, around a shifting axis, which varies in position with the point of contact.

In some few instances the long axis of the articulating surface is parallel rather than transverse to the long axis, and as the movement then takes place around a more or less conic surface, the joint is termed a *trochoid* or pulley—*e. g.,* the odonto-atlantal and the radio-ulnar. In the former the collar formed by the atlas and its transverse ligament rotates around the vertical odontoid process of the axis. In the latter the head of the radius revolves around its own long axis upon the ulna, giving rise to the movements of pronation and supination of the hand. The axis around which these two movements take place is continued through the head of the radius to the styloid process of the ulna.

2. Biaxial Joints.—In this group the articulating surfaces are unequally curved, though intersecting each other. When the surfaces lie in the same direction, the joint is termed an *ovoid* joint—*e. g.*, the radio-carpal and the atlanto-occipital. As the axes of these surfaces are vertical to each other, the movements permitted by the former joint are flexion, extension, adduction, and abduction, combined with a slight amount of circumduction; the latter joint permits of flexion and extension of the head, with inclination to either side. When the surfaces do not take the same direction, the joint, from its resemblance to the surfaces of a saddle, is termed a saddle-joint—*e. g.*, the trapezio-metacarpal. The movements permitted by this joint are also flexion, extension, adduction, abduction, and circumduction.
3. Polyaxial Joints.—In this group the convex articulating surface is a segment of a sphere, which is received by a socket formed by the opposing articulating surface. In such a joint, termed an *enarthrodial* or ball-and-socket joint,—*e. g.*, the shoulder-joint, hip-joint,—the distal bone revolves around an indefinite number of axes, all of which intersect one another at the center of rotation. For simplicity, however, the movement may be described as taking place around axes in the three ordinal planes—viz., a transverse, a sagittal, and a vertical axis. The movements around the transverse axis are termed flexion and extension; around the sagittal axis, adduction and abduction; around the vertical axis, rotation. When the bone revolves around the surface of an imaginary cone, the apex of which is the center of rotation and the base the curve described by the hand, the movement is termed circumduction.

2. *Amphiarthroses.*—In this division are included all those joints which permit of but slight movement—*e. g.*, the intervertebral, the interpubic, and the sacro-iliac joints. The surfaces of the opposing bones are united and held in position largely by the intervention of a firm, elastic disc of fibro-cartilage. Each joint is also strengthened by ligaments.
3. *Synarthroses.*—In this division are included all those joints in which the opposing surfaces of the bones are immovably united, and hence do not permit of any movement—*e. g.*, the joints between the bones of the skull.

The Vertebral Column.—In all static and dynamic states of the body the vertebral column plays a most essential rôle. Situated in the middle of the back of the trunk, it forms the foundation of the entire skeleton. It is composed of a series of superimposed bones, termed vertebræ, which increase in size from above downward as far as the brim of the pelvic cavity. Superiorly, it supports the skull; laterally, it affords attachment for the ribs, which in turn support the weight of the upper extremities; below, it rests upon the pelvic bones, which transmit the weight of the body to the inferior extremities. The bodies of the vertebræ are united one to another by tough elastic discs of fibro-cartilage, which, collectively, constitute about one quarter of the length of the vertebral column. The vertebræ are held together by ligaments situated on the anterior and posterior surfaces of their bodies, and by short, elastic ligaments between the neural arches and processes. These structures combine to render the vertebral column elastic and flexible, and enable it to resist and diminish the force of shocks communicated to it.

The amphiarthrodial character of the intervertebral joint endows the entire column with certain forms of movement which are necessary to the performance of many body activities. While the range of movement between any two vertebræ is slight, the sum total of movement of the entire series of vertebræ is considerable. In different regions of the column the character, as well as the range of movement, varies in accordance with the form of the vertebræ and the inclination of their articular processes. In the cervical and lumbar regions extension and flexion are freely permitted, though the former is greater in the cervical, the latter in the lumbar region, especially between the fourth and fifth vertebræ. Lateral flexion takes place in all portions of the column, but is particularly marked in the cervical region. A rotatory movement of the column as a whole takes place through an angle of about twenty-eight degrees. This is most evident in the lower cervical and dorsal regions.

The skeleton may, therefore be regarded as a highly developed framework, which determines not only the form of the body, and affords support and protection to the various softer organs and tissues, but also, through the mobility of its joints, permits of a great variety of complicated movements.

GENERAL PHYSIOLOGY OF MUSCLE TISSUE.

The **muscle tissue,** which closely invests the bones of the body, and which is familiar to all as the flesh of animals, is the immediate cause of the active movements of the body. This tissue is grouped in masses of varying size and shape, which are technically known as muscles. The majority of the muscles of the body are connected with the bones of the skeleton in such a manner that, by an alteration in their form, they can change not only the position of the bones with reference to one another, but can also change the individual's relation to surrounding objects. They are, therefore, the active organs of both motion and locomotion, in contradistinction to the bones and joints, which are but passive agents in the performance of the corresponding movements. In addition to the muscle masses which are attached to the skeleton, there are also other collections of muscle tissue surrounding cavities such as the stomach, intestine, blood-vessels, etc., which impart to their walls motility, and so influence the passage of a material through them.

Muscles produce movement of the structures to which they are attached by the property with which they are endowed of changing their shape, shortening or *contracting* under the influence of a stimulus transmitted to them from the nervous system. Muscles are therefore divided into:

1. *Voluntary muscles,* comprising those whose activity is called forth by stimuli of the nerves as the result of an act or effort of volition.
2. *Involuntary muscles,* comprising those whose activity is entirely independent of the volition.

The voluntary muscles are also known from their attachment to the skeleton as *skeletal,* and from their microscopic appearance as *striped* muscles. The involuntary muscles, from their relation to the viscera of the body, are known also as *visceral,* and from their microscopic appearance as plain or smooth muscles.

General Structure of Muscles.—All skeletal muscles consist of a central fleshy portion, the body or belly, which is provided at either extremity with a tendon in the form of a cord or membrane by which it is attached to the bones. The body is the contractile region, the source of activity; the tendon is a passive region, and merely transmits the activity to the bones.

A skeletal muscle is a complex organ consisting of muscular fibers, connective tissue, blood-vessels, and lymphatics. The general body of the muscle is surrounded by a dense layer of connective tissue, the *epimysium*, which blends with and partly forms the tendon; from its inner surface septa of connective tissue pass inward and group the muscle-fibers into larger and smaller bundles, termed *fasciculi*. The fasciculi, invested by this special sheath, the *perimysium*, are irregular in shape, and vary considerably in size. The fibers of the fasciculi are separated from one another and supported by a delicate connective tissue, the *endomysium*. The connective tissue thus surrounding and penetrating the muscle binds its fibers into a distinct organ, and affords support to blood-vessels, nerves, and lymphatics. The muscle fibers are arranged parallel to one another, and their direction is that of the long axis of the muscle. In length they vary from thirty to forty millimeters, and in diameter from twenty to thirty micromillimeters.

The **vascular supply** to the muscles is very great, and the disposition of the capillary vessels, with reference to muscle-fiber, is very characteristic. The arterial vessels, after entering the muscle, are supported by the perimysium; in this situation they give off short, transverse branches, which immediately break up into a capillary network of rectangular shape, within which the muscle-fibers are contained. The muscle-fiber in intimate relation with the capillary is bathed with lymph derived from it. Its contractile substance, however, is separated from the lymph by its own investing membrane, through which all interchange of nutritive and waste materials must take place. Lymphatics are present in muscle, but are confined to the connective tissue, in the spaces of which they have their origin.

The **nerves** which carry the stimuli to a muscle enter near its geometric center. Many of the fibers pass directly to the muscle-fibers with which they are connected; others are distributed to blood-vessels. Every muscle-fiber is supplied with a special nerve-fiber, except in those instances where the nerve trunks entering a muscle do not contain so many fibers as the muscle. In such cases the nerve-fibers divide, until the number of branches equals the number of muscle-fibers. The individual muscle-fiber is penetrated near its center by the nerve, the ends being practically free from nerve influence. The stimulus that comes to the muscle fiber acts primarily upon its center, and then travels in both directions to the ends.

Histology of the Skeletal Muscle-fiber.—A muscle-fiber consists of a transparent elastic membrane, the *sarcolemma,* in which is contained the true muscle element. Examined microscopically, the fiber presents a series of alternate dim and bright bands, giving to it a striated appearance.

When the bright band is examined with high magnifying powers, a fine, dark line is seen crossing it transversely. It was supposed by Krause to be the optic expression of a membrane which divides the cavity of the sarcolemma into a series of compartments, each of which contains a dim band of sarcous or muscle substance, bounded at either extremity with the half of a bright band. This membrane has since been resolved into a row of granules.

The muscle-fiber also exhibits a longitudinal striation, indicating that it is composed of fibrillæ, placed side by side and embedded in some interfibrillar substance, to which the name *sarcoplasm* has been given. The fibrillæ, which are arranged longitudinally to the long axis of the fiber, are grouped by the intervening material into bundles of varying size, the *muscle columns.* The fibrillæ which extend throughout the length of the fiber are not of uniform thickness, but present at regular intervals well-marked constrictions.

In the region of the dim band the fibrilla presents itself in the form of a homogeneous prismatic rod, termed *sarcostyle,* separated from neighboring rods by a slight amount of sarcoplasm. Between two successive rods is found a dark granule, united by a thin band of similar material to the ends of the rods. The transverse row of granules corresponds to Krause's membrane.

In the region of the granules there is a diminution of the sarcous substance, but an increase in the amount of sarcoplasm, and as the latter is more transparent than the former, the fiber presents at this point a conspicuous bright band. Rollet considers the sarcostyles to be preëxistent, not the result of post-mortem or chemic changes, and the seat of the contractile elements. The sarcoplasm is a passive material similar in its properties to protoplasm.

Brücke has shown that when the muscle-fiber is examined under crossed Nicol prisms the dim band appears bright and the bright band appears dim against a dark background, indicating that the former is doubly refractile, or anisotropic, the latter singly refractile, or isotropic. The fiber, therefore, appears to be composed of alternate discs of anisotropic and isotropic substance.

Structure of Non-striated Muscle-fiber.—As the name implies, the involuntary fiber is non-striated, being apparently uniform and homogeneous in appearance. When isolated, the fiber presents itself in the form of an elongated fusiform cell, varying from $\frac{1}{10}$ to $\frac{1}{600}$ of an inch in length. In some animals the fiber exhibits a longitudinal striation, as if it were composed of fibers. The cell is surrounded by a thin, elastic membrane, and contains a distinct oval nucleus. The fibers are usually arranged in bundles and lamellæ, and held together by a cement substance and connective tissue. This non-striated muscle tissue is found in the muscularis mucosæ of the alimentary canal as well as in the muscular walls of the stomach and intestines, in the posterior part of the trachea, in the bronchial tubes, in the walls of the blood-vessels, and in many other situations.

Chemic Composition of Muscle.—The chemic composition of muscle is imperfectly understood, owing to the fact that some of its constituents undergo a spontaneous coagulation after death, and that the chemic methods employed also tend to alter its normal composition. When fresh muscle is freed from fat and connective tissue, frozen, rubbed up in a mortar, and expressed through linen, a slightly yellow, syrupy, alkaline, or neutral fluid is obtained, known as *muscle plasma.* This fluid at normal temperature coagulates spontaneously, and resembles in many respects the coagulation of blood plasma. The coagulum subsequently contracts and squeezes out an acid *muscle serum.* The coagulated mass is termed *myosin.* This proteid belongs to the class of globulins. Inasmuch as it is not present in living muscle, and makes its appearance only in the as yet living muscle plasma, it is probable that it is derived from some preexisting substance, which is supposed to be *myosinogen.* Myosin is digested by pepsin and trypsin. According to Halliburton, muscle plasma contains the following proteid bodies: Myosinogen, paramyosinogen, albumin, myoalbumose; all of which differ in chemic composition and respond to various chemic and physical reagents.

Ferment bodies, such as pepsin and diastase; non-nitrogenized bodies, such as glycogen, lactic and sarcolactic acids, fatty bodies, and inosite; nitrogenized extractives—*e. g.,* urea, uric acid, kreatinin, as well as inorganic salts, have been obtained from the muscle serum.

Metabolism in Muscles.—The chemic changes which underlie the transformation of energy in living muscles are very active and complex.

As shown by an analysis of the blood flowing to and from the resting muscle, it has, while passing through the capillaries, lost oxygen and gained carbon dioxid. The amount of oxygen absorbed by the muscle (nine per cent.) is greater than the amount of CO_2 given off (6.7 per cent.). There is no parallelism between these two processes, as CO_2 will be given off in the absence of oxygen, or in an atmosphere of nitrogen.

In the active or contracting muscle both the absorption of oxygen and the production of CO_2 are largely increased, but the ratio existing between them differs considerably from that of the resting muscle, for the quantity of oxygen absorbed amounts to 11.26 per cent., the quantity of CO_2 to 10.8 per cent. (Ludwig). Moreover, in a tetanized muscle the quantity of CO_2 given off may be largely in excess of the oxygen absorbed. From these facts it is evident that the energy of the contraction does not depend upon the direct oxidation of certain substances, but upon the decomposition of some unstable compound of high potential energy, rich in carbon and oxygen. When the muscle is active, its tissue changes from a neutral to an acid reaction, from the development of sarcolactic and possibly phosphoric acids. The amount of glycogen present in muscle (0.43 per cent.) diminishes, but muscles wanting in glycogen, nevertheless, retain their power of contraction. Water is absorbed. The amount of urea is not materially increased by muscular activity, unless it is excessive and prolonged, and then only in the absence of a sufficient quantity of non-nitrogenized material. Coincident with muscle contraction, the blood-vessels become widely dilated, leading to a large increase in the blood-supply and a rapid removal of products of decomposition.

Rigor Mortis.—A short time after death the muscles pass into a condition of extreme rigidity or contraction, which lasts from one to five days. In this state they offer great resistance to extension, their tonicity disappears, their cohesion diminishes, their irritability ceases. The time of the appearance of this post-mortem or cadaveric rigidity varies from a quarter of an hour to seven hours. Its onset and duration are influenced by the condition of the muscular irritability at the time of death. When the irritability is impaired from any cause, such as disease or defective blood-supply, the rigidity appears promptly, but is of short duration. After death from acute diseases, it is apt to be delayed, but to continue for a longer period.

The rigidity appears first in the muscles of the lower jaw and neck; next in the muscles of the abdomen and upper extremities; finally in the trunk and lower extremities. It disappears in practically the same order.

Chemic changes of a marked character accompany this rigidity. The muscle becomes acid in reaction from the development of sarcolactic acid; it gives off a large quantity of carbonic acid, and is shortened and diminished in volume.

The immediate cause of the rigidity appears to be a coagulation of the *myosinogen* within the sarcolemma, with the subsequent formation of *myosin* and muscle serum. In the early stages of coagulation restitution is possible by the circulation of arterial blood through the vessels. The final disappearance of this contraction is due to the action of acids dissolving the myosin, and possibly to putrefactive changes.

Source of Muscular Energy.—According to most experimenters, it is certain that normal muscle activity is not dependent on the metabolism of nitrogenous materials, inasmuch as its chief end product, urea, is not increased. The marked production of CO_2 points to the combustion of some non-nitrogenous matter,—*e. g.*, glycogen,—especially as this substance disappears during muscular activity. Muscles wanting in glycogen are, nevertheless, capable of contracting for some time. Moreover, there is no proof of the direct combustion of glycogen or any other carbohydrate. It has been suggested by Hermann that the energy of a muscular contraction may be due to the splitting and subsequent re-formation of a complex body belonging neither to the carbohydrates nor to the fats, but to the albumins. To this body the term inogen has been applied. This complex molecule, the product of the metabolic activity of the muscle cell, in undergoing decomposition would yield CO_2, sarcolactic acid, and a proteid residue resembling *myosin*. With the cessation of the contraction, the muscle protoplasm recombines the proteid residue with oxygen, carbohydrates, and fats, and again forms inogen.

The phenomena of rigor mortis support such a view. At the moment of this contraction the muscle gives off CO_2 in large amount, the muscle becomes acid, and myosin is formed. There is thus a close analogy between the two processes; in other words, a contraction is a partial death of the muscle. As to what becomes of the myosin formed during a contraction, nothing is known. It may be used in the formation of new inogen.

The Physical Properties of Muscle Tissue.—The *consistency* of muscle tissue varies considerably, according to the different states of the muscle. In a state of tension it is hard and resistant; when free from tension, it is soft and fluctuating, whether the muscle is contracting or resting. Tension alone produces hardness. The *cohesion* of muscle tissue is less than that of connective tissue, and is broken more readily. Cohesion resists traction and pressure, and lasts as long as irritability remains.

The *elasticity* of a muscle, though not great is almost perfect. After being extended by a weight, it returns to its natural form. The limit of elasticity, however, is soon passed. A weight of 50 or 100 grams will overcome the elasticity so that it will not return to its natural length. In inorganic bodies the extension is directly proportional to the extending weight, and the line of extension is straight. With muscles, the extension is not proportional to the weight. While at first it is marked, the elongation diminishes as the weight increases by equal increments, so that the line of extension becomes a curve. In other words, the elasticity of a passive muscle augments with increased extension. On the contrary, the elasticity of an active is less than that of a passive muscle, for it is elongated more by the same weight, as shown by experiment.

Tonicity is a property of all muscles in the body, in consequence of being normally stretched to a slight extent beyond their natural length. This may be due to the action of antagonistic muscles, or to the elasticity of the parts of the skeleton to which they are attached. This is shown by the shortening of the muscle which takes place when it is divided. Muscular tonus plays an important rôle in muscular contraction. Being always on the stretch, the muscle loses no time in acquiring that degree of tension necessary to its immediate action on the bones. Again, the working power of a muscle is increased by the presence of some resistance to the act of contraction. According to Marey, the amount of work is considerably increased when the muscular energy is transmitted by an elastic body to the mass to be moved, while at the same time, the shock of the contraction is lessened. The position of a passive limb is the resultant also of the elastic tension of antagonistic groups of muscles.

Muscle excitability or **contractility** are terms employed to denote that property of muscle tissue in virtue of which it contracts or shortens in response to various excitants or stimuli. Though usually associated with the activity of the nervous system, it is nevertheless, an independent endowment, and persists after all nervous connections are destroyed. If the nerve terminals be destroyed, as they can be by the introduction of curara into the system, the muscles become completely relaxed and quiescent. The strongest stimuli applied to the nerves fail to produce a contraction. Various external stimuli applied directly to the muscle substance produce at once the characteristic contraction. The excitability of muscle is therefore an inherent property, dependent on its nutrition, and persisting as long as it is supplied with proper nutritive materials and surrounded by those external conditions which maintain its chemic or physical integrity.

Muscle Contractions.—All muscle contractions occurring in the body under normal physiologic conditions are either *voluntary,* caused by a volitional effort and the transmission of a nerve impulse from the brain through the spinal cord and nerves to the muscles, or *reflex,* caused by a peripheral stimulation and the transmission of a nerve impulse to the spinal cord, to be reflected outward through the same nerves to the muscles. In either case the resulting contraction is essentially the same. The *normal* or *physiologic stimulus* which provokes the muscular contraction is a nerve impulse the nature of which is unknown, but is perhaps allied to a molecular disturbance. After removal from the body, muscles remain in a state of rest, inasmuch as they possess no spontaneity of action. Though consisting of a highly irritable tissue, they can not pass from the passive to the active state except upon the application of some form of stimulation.

The stimuli which are capable of calling forth a contraction may be divided into—

1. Mechanical.
2. Chemic.
3. Physical.
4. Electric.

Every mechanical stimulus of a muscle,—*e. g.,* pick, cut, or tap,—provided it has sufficient intensity, and is repeated with sufficient rapidity, will cause not only a single contraction, but a series of contractions.

All chemic agents which impair the chemic composition of the muscle with sufficient rapidity—*e. g.,* hydrochloric acid, acetic and oxalic acids, distilled water injected into the vessels, etc.—act as stimuli, and produce single and multiple contractions. Physical agents, as heat and electricity, also act as stimuli. A muscle heated rapidly to 30° C. contracts vigorously, and reaches its maximum at 45° C. Of all forms of stimuli, the electric is the most generally used. Two forms are used—the induced current and the make-and-break of a constant current.

Changes in a Muscle During Contraction.—When a muscle is stimulated, either indirectly through the nerve or directly by any external agent, it undergoes a series of changes, which relate to its form, volume, optic, physical, chemic, and electric properties. These changes, in their totality, constitute the muscular contraction.

1. *Form.*—The most obvious change is that of form. The fibers become shorter in their longitudinal and wider in their transverse diameters, and the muscle as a whole becomes shorter and thicker. The degree of shortening may amount to thirty per cent. of the original length.
2. *Volume.*—The increase in transverse diameter does not fully compensate for the diminution in length, for there is at the moment of contraction a slight shrinkage in volume, which has been attributed to a compression of air in its interstices.
3. *Optic Changes.*—If a muscle-fiber be examined microscopically during its contraction, it will be observed that when the contraction wave begins, both bright and dim bands diminish in height and become broader, though this change is more noticeable in the region of the bright band. This Englemann attributes to a passage of fluid material from the bright into the dim band. At the time of relaxation there is a return of this material, and the fiber assumes its original shape and volume. As the contraction wave reaches its maximum, the optic properties of both the isotropic and anisotropic bands change. The *former,* which was originally clear, now becomes darker and less transparent, until at the crest of the wave it assumes the appearance of a distinct dark band. The *latter*, the anisotropic, which was originally dim, now becomes, in comparison, clear and light. This change in optic appearance is due to an increase in refrangibility of the isotropic and a decrease in the anisotropic bands coincident with the passage of fluid from the former into the latter. There is at the height of the contraction a complete reversal in the positions of the striations. At a certain stage between the beginning and the crest of the wave these is an intermediate point, at which the striæ almost entirely

disappear, giving to the fiber an appearance of homogeneity. There is, however, no change in refractive power, as shown by the polarizing apparatus. After the contraction wave has reached the stage of greatest intensity, there is a reversal of the foregoing phenomena, and the fiber returns to its original condition, which is one of relaxation.

Physical Changes.—The extensibility of muscle is increased during the contraction, the same weight elongating the fibers to a greater extent than during rest. The elasticity, or its power of returning to its original form is correspondingly diminished.

Chemic Changes.—The metabolism of muscle during the contraction is very active. There is an increase in the production of carbon dioxid and in the absorption of oxygen. The muscle changes from an alkaline or neutral to an acid reaction, from the development of sarcolactic acid. The muscle also becomes warmer. The electric changes will be treated of in connection with nerves.

Transmission of the Contraction Wave.—Normally, when a muscle is stimulated by the nerve impulse, the shortening and thickening of the fibers begin at the end organ and travel in opposite directions to the ends of the muscle. This change propagates itself in a wave-like manner, and has been termed the contraction wave. If a stimulus be applied directly to the end of a long muscle, the contraction wave passes along its entire length to the opposite extremity, in virtue of the conductivity of muscular tissue. The rapidity of the propagation varies in different animals—in the frog, from three to four meters a second, in man, from ten to thirteen meters. The length of the wave varies from 200 to 400 millimeters.

Graphic Record of a Muscle Contraction.—The changes in the form of a muscle during contraction and relaxation have been carefully studied by recording the muscle movement by means of an attached lever, the end of which is allowed to rest upon a moving surface. The time relations of all phases of the muscular movement are obtained by placing beneath the lever a pen atached to an electromagnet thrown into action by a tuning-fork vibrating in hundredths of a second. A marking lever records simultaneously the moment of stimulation.

Single Contraction.—When a single electric induction shock is applied to a nerve close to the muscle, the latter undergoes a quick pulsation, speedily returning to its former condition. As shown by the muscle curve (see Fig. 4), there is between the moment of stimulation and the beginning of the contraction a short but measurable period, known as the *latent period,* during which certain chemic changes are taking place preparatory to the exhibition of the muscle movement. Even when the electric stimulus is applied directly to the muscle, a latent period, though shorter, is observable. The duration of this period in the skeletal muscles of the frog has been estimated at 0.01 of a second; but it has been shown by the employment of more accurate methods and the elimination of various external influences to be much less—not more than 0.0033 to 0.0025 of a second.

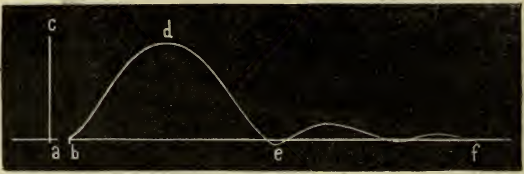


Fig. 4.—Muscle Curve Produced by a Single Induction Shock Applied to a Muscle.—(*Landois.*)

a–f. Abscissa. a–c. Ordinate. a–b. Period of latent stimulation. b–d. Period of increasing energy. d–e. Period of decreasing energy. e–f. Elastic after-vibrations.

The *contraction* follows the latent period. This begins slowly, rapidly reaches its maximum, and ceases. This has been termed the stage of rising or increasing energy. The time occupied in the stage of shortening is about 0.04 of a second, though this will depend on the strength of the stimulus, the load with which the muscle is weighted, and the condition of the muscle irritability.

The *relaxation* immediately follows the contraction. This takes place at first slowly, after which the muscle rapidly returns to its original length. This is the period of falling or decreasing energy, and occupies about 0.05 of a second. The whole duration of a muscle contraction occupies, therefore, about 0.1 of a second.

Residual or after-vibrations are frequently seen which are due to changes in the elasticity of the muscle. The *amplitude* of the contraction depends upon the condition of the muscle, the load, the strength of stimulus, etc.

Contraction of Non-striated Muscle.—The curve obtained by registration of the contraction of non-striated muscle shows that it is similar in many respects to that of the striated muscle, except that the duration of the former is considerably longer than that of the latter.

Action of Successive Stimuli.—If a series of successive stimuli be applied to a muscle, the effect will be different according to the rapidity with which they follow one another. If the second stimulus be applied at the termination of the contraction due to the first stimulus, a second contraction follows, similar in all respects to the first. A third stimulus produces a third contraction, and so on until the muscle becomes exhausted. If the second stimulus be applied during either of the two periods of the first contraction, the effects of the two stimuli will be added together and the second contraction will add itself to the first. The maximum contraction is obtained when the second stimulus is applied $\frac{1}{20}$ of a second after the first.

Tetanus.—When a series of stimuli are applied to a muscle, following one another with median rapidity, the muscle does not get time to relax in the intervals of stimulation, but remains in a state of vibratory contraction, which may be regarded as incipient tetanus, or clonus. As the stimulation increases in frequency, the vibrations become invisible, being completely fused together. There is, nevertheless, during the tetanic condition a series of continuous contractions and relaxations taking place. After a varying length of time the muscle becomes fatigued, and notwithstanding the stimulation, begins slowly to elongate. The number of stimuli necessary a second for the production of tetanus varies in different animals—*e. g.*, 2 to 3 for muscles of the tortoise; 10 for muscles of the rabbit; 15 to 20 for the frog; 70 to 80 for birds; 330 to 340 for insects.

A voluntary contraction in man may be regarded as a state of tetanus, for if the curve of a voluntary movement be examined, it will be found to consist of intermittent vibrations. The simplest voluntary movement of a muscle, however rapidly it may take place, last longer than a single muscular contraction due to an induction shock. The most rapid voluntary contraction is the result of from 2.5 to 4 stimulations a second, and has a duration of from 0.041 to 0.064 of a second. A continuous voluntary contraction is an incomplete tetanus. The number of stimuli sent to the muscle is on the average, 16 to 18 for rapid contractions, 8 to 12 for slow contractions.

The Production of Heat and Its Relation to Mechanical Work.—The transformation of energy which takes place during a muscle contraction, and which is dependent upon chemic changes occurring at that time, manifests itself as heat and mechanical work. While heat is being evolved continuously during the passive condition of muscles, the amount of heat is largely increased during general muscle contraction. A skeletal muscle of a frog—*e. g.*, the gastrocnemius,—when removed from the body, shows, after tetanization, an increase in its temperature of from 0.14° to 0.18° C., and after a single contraction of from 0.001° to 0.005° C. While every muscular contraction is attended by an increase in heat production, the amount so produced will vary in accordance with certain conditions—*e. g.*, tension, work done, fatigue, circulation of blood, etc.

Tension.—The greater the tension of a muscle, the greater, other conditions being equal, is the amount of heat evolved. When the ends of a muscle are fastened so that no shortening is possible during stimulation, the maximum of heat production is reached. In the tetanic state the great increase in temperature is due to the tension of antagonistic and strongly contracted muscles. The evolution of heat, therefore, bears a relation to the resistance against which the muscle is acting.

Mechanical Work.—If a muscle contracts, loaded by a weight just sufficient to elongate it to its original length, heat is evolved, but no mechanical work is done, all the energy liberated manifesting itself as heat. When the weight which has been lifted is removed from the muscle at the height of contraction, external work is done. In this case the amount of heat liberated is less, owing to the work done, for some of the heat generated is transformed into mechanical motion. According to the law of the conservation of energy, the amount of heat disappearing should correspond in heat units to the number of foot-pounds produced by muscular contraction.

Muscle Sound.—Providing a muscle be kept in a state of tension during its contraction, the intermittent variations of its tension cause the muscle to emit an audible sound. If the muscle be tetanized by induction shocks, the pitch of the sound corresponds with the number of stimuli a second. A voluntary contraction is attended by a tone having a vibration frequency of about thirty-six a second, which is, however, the first overtone of the true muscle tone, which is caused by a contraction frequency of about eighteen a second.

This low tone is inaudible, from the small number of vibrations a second.

Muscle Fatigue.—Prolonged or excessive muscular activity is followed by a diminution in the power of producing work and by an increase in the duration of the muscular contractions. Fatigue is accompanied by a feeling of stiffness, soreness, and lassitude, referable to the muscles themselves. In the early stages of muscular fatigue the contractions increase in height and duration, to be followed by a progressive decrease in height, but an increase in duration, until the muscle becomes exhausted. The cause of the fatigue is the production and accumulation of decomposition products, such as phosphoric acid and phosphate of potassium, CO_2, etc. A fatigued muscle is rapidly restored by the injection of arterial blood.

Work Done.—Muscles are machines capable of doing a certain amount of work, by which is meant the raising of a weight against gravity or the overcoming of some resistance. The work done is calculated by multiplying the weight by the distance through which it is raised. Thus, if a muscle shortens four millimeters and raises 250 grams, it does work equal to 1,000 milligram-meters, or one gram-meter. If a muscle contracts without being weighted, no work is done. Equally, when the muscle is over-weighted so that it is unable to contract, no work it done. The amount of work a muscle can do will depend upon the area of its transverse section, the length of its fibers, and the amount of the weight. The amount of work a laborer of 70 kilograms weight performs in eight hours averages 105,605 kilogram-meters, or 340.2 foot-tons.

SPECIAL PHYSIOLOGY OF MUSCLES.

The individual muscles of the axial and appendicular portions of the body are named with reference to their shape, action, structure, etc.—*e. g.,* deltoid, flexor, penniform, etc. In different localities a group of muscles having a common function is named in accordance with the kind of motion it produces or gives rise to—*e. g.,* groups of muscles which alternately bend or straighten a joint, or alternately diminish or increase the angular distance between two bones, are known respectively as *flexors* and *extensors;* such muscle groups are in association with ginglymus joints. Muscles which turn the bone to which they are attached around its own axis without producing any great change of position are known as *rotators,* and are in association with the enarthrodial or ball-and-socket joints. Muscles which impart an angular movement of the extremities to and from the median line of the body are termed *abductors* and *adductors.*

In addition to the actions of individual groups of muscles in causing special movements in some regions, several groups of muscles are coördinated for the accomplishment of certain definite functions —*e. g.,* muscles of respiration, mastication, expression. The coördination of axial and appendicular muscles enables the individual to assume certain postures, such as standing and sitting; to perform various acts of locomotion, as walking, running, swimming, etc.

Levers.—The function or special mode of action of individual muscles can be understood only when the bones with which they are connected are regarded as levers whose fulcra or fixed points lie in the joints where the movement takes place, and when the muscles are considered as sources of power for imparting movement to the levers, with the object of overcoming resistance or raising weights.

In mechanics, levers of three kinds or orders are recognized, according to the relative position of the *fulcrum* or axis of motion, the applied power, and the weight to be moved. (See Fig. 5.)

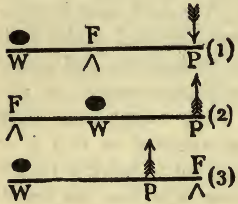


FIG. 5.—THE THREE ORDERS OF LEVERS.

In levers of the *first order* the fulcrum, F, lies between the weight or resistance, W, and the power of moving force, P. The distance P–F is known as the power arm, the distance W–F as the weight arm. As an example of this form of lever in the human body may be mentioned:

1. The elevation of the trunk from the flexed position. The axis of movement, the fulcrum, lies in the hip-joint; the weight, that of the trunk, acting as if concentrated at its center of gravity, lies between the shoulders; the power, the contracting muscles attached to the tuberosity of the ischium. The opposite movement is equally one of the first order, but the relative positions of P and W are reversed.
2. The skull in its movements backward and forward upon the atlas.

In levers of the *second order* the weight lies between the power and the fulcrum. As an illustration of this form of lever may be mentioned:

1. The depression of the lower jaw, in which movement the fulcrum is the temporomaxillary articulation; the resistance, the tension of the elevator muscles; the power, the contraction of the depressor muscles.
2. The raising of the body on the toes—F being the toes, W the weight of the body acting through the ankle, P the gastrocnemius muscle acting upon the heel bone.

In levers of the *third order* the power is applied at a point lying between the fulcrum and the weight. As examples of this form of lever may be mentioned:

1. The flexion of the forearm—F being the elbow-joint, P the contracting biceps and brachialis anticus muscles applied at their insertion, W the weight of the forearm and hand.
2. The extension of the leg on the thigh.

When levers are employed in mechanics, the object aimed at is the overcoming of a great resistance by the application of a small force acting through a great space, so as to obtain a mechanical advantage. In the mechanism of the human body the reverse generally obtains—viz., the overcoming of a small resistance by the application of a great force acting through a small space. As a result, there is a gain in the extent and rapidity of movement of the lever. The power, however, owing to its point of application, acts at a great mechanical disadvantage in many instances, especially in levers of the third order.

Postures.—Owing to its system of joints, levers, and muscles, the human body can assume a series of positions of equilibrium, such as standing and sitting, to which the name posture has been given. In order that the body may remain in a state of stable equilibrium in any posture, it is essential that the vertical line passing through the center of gravity shall fall within the base of support.

Standing is that position of equilibrium in which a line drawn through the center of gravity falls within the area of both feet placed on the ground. This position is maintained:

1. By firmly fixing the head on the top of the vertebral column by the action of the muscles on the back of the neck.
2. By making the vertebral column rigid, which is accomplished by the longissimus dorsi and the quadratus lumborum muscles.

This having been accomplished, the center of gravity falls in front of the tenth dorsal vertebra; the vertical line passing through this point falls behind the line connecting both hip-joints. In consequence, the trunk is not balanced on the hip-joints, and would fall backward were it not prevented by the contraction of the rectus femoris muscle and ligaments. At the knees and ankles a similar balancing of the parts above is brought about by the action of various muscles. When the entire body is in the erect or military position, the arms by the sides, the center of gravity lies between the sacrum and the last lumbar vertebra, and the vertical line touches the ground between the feet and within the base of support.

Sitting erect is a condition of equilibrium in which the body is balanced on the tubera ischii, when the trunk and head together form a rigid column. The vertical line passes between the tubera.

Locomotion is the act of transferring the body, as a whole, through space, and is accomplished by the combined action of its own muscles. The acts involved consist of walking, running, jumping, etc.

Walking is a complicated act, involving almost all the voluntary muscles of the body, either for purposes of progression or for balancing the head and trunk, and may be defined as a progression in a forward horizontal direction, due to the alternate action of both legs. In walking, one leg becomes for the time being, the active or supporting leg, carrying the trunk and head; the other, the passive but progressive leg, to become in turn the active leg when the foot touches the ground. Each leg, therefore, is alternately in an active and a passive state.

Running is distinguished from walking by the fact that, at a given moment, both feet are off the ground and the body is raised in the air.

While the limits of a compend do not permit of a description of the origin, insertion, and mode of action of the individual muscles of the body, it has been thought desirable to call attention to a few of the principal muscles whose function it is to produce special forms of movement, as well as locomotion. (See Fig. 6.) The erect position is largely maintained by the fixation of the spinal column and the balancing of the head upon its upper extremity; the former is accompanied by the *erector spinæ* muscle, named from its function and its fleshy continuations, situated on each side of the vertebral column. Arising from the pelvis and lumbar vertebræ, this muscle passes upward, and is attached by its continuations to all the vertebræ. Its action is to extend the vertebral column and to maintain the erect position. The head is balanced upon the top of the vertebral column by the combined action of the trapezius and suboccipital muscles forming the nape of the neck, and by the *sterno-cleido-mastoid* muscle. This latter muscle arises from the inner third of the clavicle and upper border of the sternum. It is inserted into the temporal bone just behind the ear. Its action is to flex the head laterally and to rotate the face to the opposite side. When both muscles act simultaneously, the head and neck are flexed upon the thorax.

The *temporal* and *masseter* muscles, situated at the side of the head, arise respectively from the temporal fossa and the zygomatic arch, and are inserted into the ramus of the lower jaw. Their action is to close the mouth and to assist in mastication. The *occipito-frontalis,* the *orbicularis palpebrarum,* and *orbicularis oris* muscles are largely concerned in wrinkling the forehead, closing the eyes and mouth, and in giving various expressions to the face.

The *deltoid* is a thick, triangular muscle covering the shoulder-joint. Arising from the outer third of the clavicle, the acromial process, and the spine of the scapula, its fibers converge to be inserted into the humerus just above its middle point. Its action is to elevate the arm through a right angle. Owing to its point of insertion it acts as a lever of the third order, but, notwithstanding the advantageous points of insertion, it acts at a considerable disadvantage, owing to the obliquity of its direction.

The *biceps* muscle, situated on the anterior aspect of the arm, arises from the upper border of the glenoid fossa and the coracoid process, and is inserted into the radius just beyond the elbow-joint. Its action is to flex and supinate the forearm and to place it in the most favorable position for striking a blow. When the forearm is fixed, it assists in flexing the arm, as in climbing.

The *triceps* muscle, situated on the back of the arm, arises from the scapula and the posterior surface of the humerus, and is inserted in the olecranon process of the ulna. In its action it directly antagonizes the biceps, namely, extending the forearm. In so doing it acts as a lever of the first order. The short distance between the muscular insertion and the fulcrum causes it to act at a great mechanical disadvantage, but there is a corresponding gain in both speed and range of movement. The muscles of the forearm are

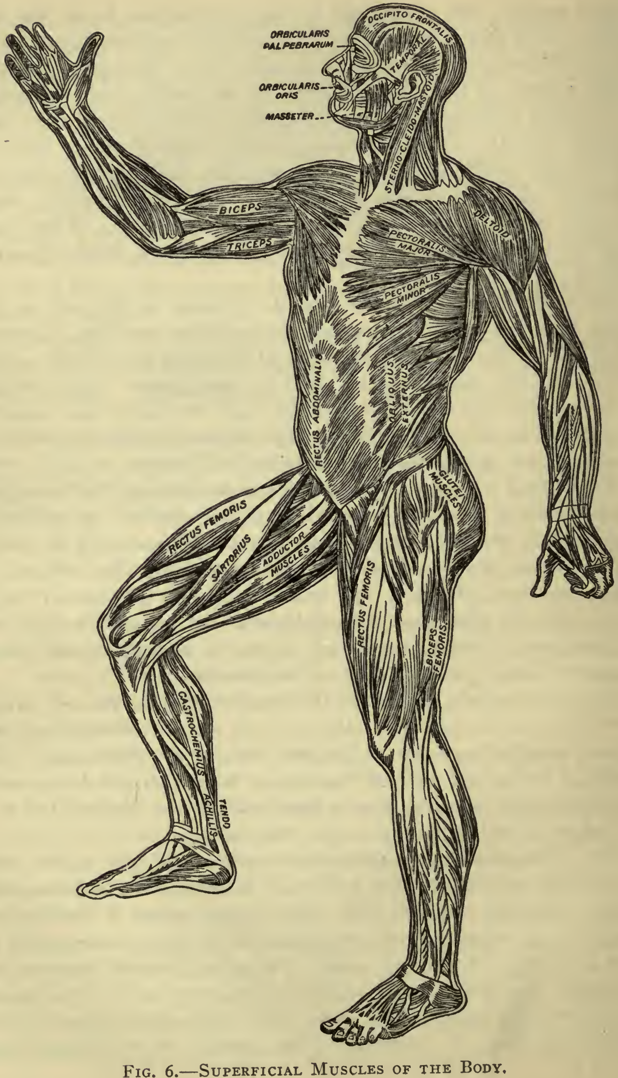

OCCIPITO FRONTALIS
ORBICULARIS PALPEBRARUM
TEMPORAL
ORBICULARIS ORIS
MASSETER
STERNO-CLEIDO-MASTOID
BICEPS
TRICEPS
DELTOID
PECTORALIS MAJOR
PECTORALIS MINOR
RECTUS ABDOMINALIS
OBLIQUUS EXTERNUS
GLUTEI MUSCLES
RECTUS FEMORIS
SARTORIUS
ADDUCTOR MUSCLES
RECTUS FEMORIS
BICEPS FEMORIS
GASTROCHEMIUS
TENDO ACHILLIS

Fig. 6.—Superficial Muscles of the Body.

very numerous. Their action is to impart to the forearm and hand a variety of movements, such as pronation, supination, flexion, extension, rotation, etc.

The *pectoralis major* and *pectoralis minor* muscles form the fleshy masses of the breast. Arising from the inner half of the clavicle, the side of the sternum, and the outer surfaces of the third, fourth, and fifth ribs anteriorly, the muscle-fibers converge to be inserted into the humerus and coracoid process. Their combined action is to adduct, flex and rotate the arm inward, and to draw the scapula downward and forward, movements necessary to the folding of the arms across the chest.

The *rectus abdominis* and the *obliquus externus* assist in forming the abdominal walls.

The *glutei* muscles are three in number, are arranged in layers, and form the fleshy masses known as the buttocks. They arise from the side of the pelvis and are attached to the femur in the neighborhood of the great trochanter. Their action is to extend the hips, to raise the body from the stooping position, and to assist in walking by firmly holding the pelvis on the thigh while the opposite leg is advanced in the forward direction.

The *rectus femoris,* with its associates, the rectus internus and rectus externus and the crureus, forms the fleshy mass on the anterior surface of the thigh. The former arises from the anterior part of the ilium, the latter from the femur. Their common tendon, which is united to the patella, is continued as the ligamentum patellæ, which is attached to the upper part of the tibia. The action of this muscular group is to extend the leg, to flex the thigh, and to raise the entire weight of the body, as in changing from the sitting to the erect position.

The *biceps femoris* muscle, situated on the outer and posterior aspect of the thigh, arises from the tuber ischii, and is inserted into the head of the fibula.

The *semimembranosus* and the *semitendinosus* muscles, situated on the inner and posterior aspect of the thigh, are inserted into the head of the tibia. Their combined action is to extend the hips and to flex the knee. Acting from below, they assist in raising the body from the stooping position.

The *gastrocnemius* muscle forms the enlargement known as the calf of the leg. It arises by two heads from the condyles of the femur. Its tendon, the tendo Achillis, is inserted into the posterior surface of the heel bone. Its action is to extend the foot and to raise the weight of the body in walking and running. On the front of the leg are numerous muscles—*e. g., tibialis anticus, peroneus longus,* etc., the action of which is to flex the foot and to antagonize the gastrocnemius.

PHYSIOLOGY OF NERVE TISSUE.

The **nerve tissue,** which unites and coördinates the various organs and tissues of the body and brings the individual into relationship with the external world, is arranged anatomically into two systems, termed the *encephalo* or *cerebro-spinal* and the *sympathetic.*

The **encephalo** or **cerebro-spinal system** consists of:

1. The brain and spinal cord, contained within the cavities of the cranium and the spinal column respectively, and
2. The cranial and spinal nerves.

The **sympathetic system** consists of:

1. A double chain of ganglia situated on each side of the spinal column and extending from the base of the skull to the tip of the coccyx.
2. Various collections of ganglia situated in the head, face, thorax, abdomen, and pelvis. All these ganglia are united by an elaborate system of intercommunicating nerves, many of which are connected with the cerebro-spinal system.

HISTOLOGY OF NERVE TISSUE.

The Neuron.—The nerve tissue has been resolved by the investigations of modern histologists into a single morphologic unit, to which the term neuron has been applied. The entire nervous system has been shown to be but an aggregate of an infinite number of neurons, each of which is histologically distinct and independent. Though having a common origin, as shown by embryologic investigations, they have acquired a variety of forms in different parts of the nervous system in the course of development. The old conception that the nervous system consisted of two distinct histologic elements, nerve-cells and nerve-fibers, which differed not only in their mode of origin, but also in their properties, their relation to each other, and their functions, has been entirely disproved.

The neuron, or neurologic unit, is histologically a nerve-cell, the surface of which presents a greater or less number of processes in varying degrees of differentiation. As represented in figure 7, the neuron may be said to consist of: (1) The nerve-cell, neurocyte, or corpus; (2) the axon, or nerve process; (3) the end tufts, or terminal branches. Though these three main histologic features are everywhere recognizable, they exhibit a variety of secondary features in different situations in accordance with peculiarities of function. Though the nerve-cell and the nerve-fiber are but part of the same neuron, it is convenient at present to describe them separately.

The Nerve-Cell.—The nerve-cell, or body of the neuron, presents a variety of shapes and sizes in different portions of the nervous system. Originally ovoid in shape, it has acquired, in course of development, peculiarities of form which are described as pyramidal, stellate, pear-shaped, spindle-shaped, etc. The size of the cell varies considerably, the smallest having a diameter of not more than $\frac{1}{3000}$ of an inch, the largest not more than $\frac{1}{400}$ of an inch. Each cell consists of granular, striated protoplasm, containing a distinct vesicular nucleus and a well-defined nucleolus. A cell membrane has not been observed. From the surface of the adult cell portions of the protoplasm are projected in various directions, which portions, rapidly dividing and subdividing, form a series of branches, termed *dendrites* or *dendrons.* In some situations the ultimate branches of the dendrites present short lateral processes, known as *lateral buds,* or *gemmules,* which impart to the branches a feathery appearance. This characteristic is common to the cells of the cortex, of the cerebrum, and of the cerebellum. The ultimate branches of the dendrites, though forming an intricate feltwork, never anastomose with one another, nor unite with dendrites of adjoining cells. According to the number of axons, nerve-cells are classified as monaxonic, diaxonic, polyaxonic: Most of the cells of the nervous system of the higher vertebrates are monaxonic. In the ganglia of the posterior or dorsal roots of the spinal and cranial nerves, however, they are diaxonic. In this situation the axons, emerging from opposite poles of the cell, either remain separate and pursue opposite directions, or unite to form a common stem, which subsequently divides into two branches, which then pursue opposite directions. (See Fig. 7.) The nerve-cell maintains its own nutrition, and presides over that of the dendrites and the axon as well. If the latter be separated in any part of its course from the cell, it speedily degenerates and dies.

The *axon,* or *nerve process,* arises from a cone-shaped projection from the surface of the cell, and is the first outgrowth from its protoplasm. At a short distance from its origin it becomes markedly differentiated from the dendrites which subsequently develop. It is characterized by a sharp, regular outline, a uniform diameter, and a hyaline appearance. In structure, the axon appears to consist of fine fibrillæ embedded in a clear, protoplasmic substance. Shäfer advocates the view that the fibrillæ are exceedingly fine tubes filled with fluid. The axon varies in length from a few millimeters to 100 cm. In the former instance the axon, at a short distance from its origin, divides into a number of branches, which form an intricate feltwork in the neighborhood of the cell. In the latter instance the axon continues for an indefinite distance as an individual struc-

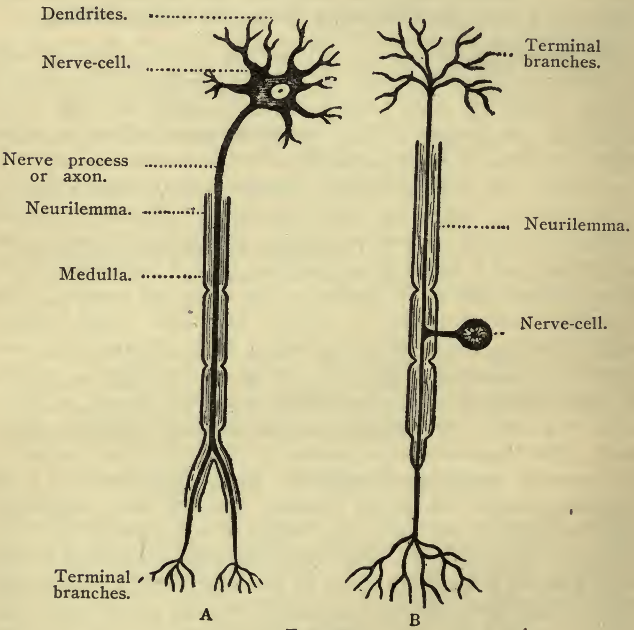

Dendrites.
Nerve-cell.
Nerve process or axon.
Neurilemma.
Medulla.
Terminal branches.
A
Terminal branches.
Neurilemma.
Nerve-cell.
B

FIG. 7.
A. Efferent neuron. B. Afferent neuron.

ture. In its course, however, especially in the central nervous system, it gives off a number of *collateral* branches, which possess all its histologic features. The long axons seem to bring the body of the cell into direct relation with peripheral organs, or with more or less remote portions of the nervous system, thus constituting association or commissural fibers.

The more or less elongated axon becomes invested, as a rule, at a short distance from the cell with nucleated oblong cells, which subsequently become modified and constitute a medullary or myelin sheath. This is invested by a thin, cellular membrane—the neurilemma. These three structures thus constitute what is known as a medullated nerve-fiber. In the central nervous system the outer sheath is frequently absent. In the sympathetic system the myelin is frequently absent, though the axon is inclosed by the neurilemma, thus constituting a non-medullated nerve-fiber.

The *end tufts* or *terminal organs* are formed by the splitting of the axon into a number of filaments, which remain independent of one another and are free from the medullary investment. The histologic peculiarities of the terminal organs vary in different situations, and in many instances are quite complex and characteristic. In peripheral organs, as muscles, glands, blood-vessels, skin, mucous membrane, the tufts are in direct organic connection with their cellular elements. In the central nervous system the tufts are in more or less intimate relation with the dendrites of adjacent neurons.

Nerve-fibers.—The axons with their secondary investments together constitute the nerve-fibers, and according as they possess or do not possess the medullary sheath, they may be divided into two groups—viz., medullated and non-medullated fibers.

Medullated Nerve-fibers.—These consist for the most part of three distinct structures:

1. An external investing sheath, tubular in shape, termed the neurilemma.
2. An intermediate semifluid substance—the medulla or myelin.
3. An internal dark thread—the axis-cylinder.

The *neurilemma* is a thin, transparent, homogeneous membrane closely adherent to the medulla. Owing to its colorless appearance, it can be seen only with difficulty in the recent condition. When treated with various reagents, it becomes distinct. Physically, it is quite resistant and elastic. Its function is doubtless that of a protective agent to the structures within.

The *medulla, myelin,* or *white substance of Schwann* completely fills the neurilemma and closely invests the axis-cylinder. In the recent condition the medulla is clear, homogeneous, semifluid, and highly refracting. In composition it is oleaginous. When the nerve is treated with various reagents which alter its composition, the medulla becomes opaque and imparts to the nerve a white, glistening appearance. The function of the medulla is quite unknown.

At intervals of about seventy-five times its diameter the medullated nerve-fiber undergoes a remarkable diminution in size, due to an interruption of the medullary substance, so that the neurilemma lies directly on the axis-cylinder. These constrictions, or *nodes of Ranvier,* taking their name from their discoverer, occur at regular intervals along the course of the nerve, separating it into a series of segments. The portion between the nodes is termed the internodal segment. It has been suggested that in consequence of the absence of the myelin at these nodes, a free exchange of nutritive material and decomposition products can take place between the axis-cylinder and the surrounding plasma.

The *axis-cylinder,* or axon, the direct outgrowth of the nerve-cell, is the most essential element of the nerve-fiber, as it alone is uniformly continuous throughout. In the natural condition it is transparent and invisible; but when treated with proper reagents, it presents itself as a pale, granular, flattened band, more or less solid and somewhat elastic. It is albuminous in composition. With high magnification the axis presents a longitudinal striation, indicating a fibrillar structure. The fibrillæ appear to be united by an intervening cement substance.

Non-medullated Nerve-fibers.—These consist, for the most part, only of the axis-cylinder, though in some portions of the nervous system a neurilemma is also present. Though much less abundant than the former variety, they are distributed largely throughout the nervous system, but are particularly abundant in the sympathetic system. Owing to the absence of a medulla, they present a rather pale or grayish appearance.

Structure of Nerve Trunks.—After their emergence from the brain and spinal cord, the nerve-fibers become bound together, by connective tissue, into the form of continuous bundles, which connect the brain and cord with all the remaining structures of the body. The bundles are technically known as *nerve trunks* or *nerves.* Each nerve is invested by a thick layer of lamellated connective tissue, known as the *epineurium*. A transverse section of a nerve shows (see Fig. 8) that it is made up of a number of small bundles of fibers, each of which possesses a separate investment of connective tissue—the *perineurium*. Within this membrane the nerve-fibers are supported by a fine stroma—the *endoneurium*. After pursuing a longer or shorter course, the nerve trunk gives off branches, which interlace very freely with neighboring branches, forming plexuses, the fibers of which are distributed to associated organs and regions of the body. From their origin to their termination, however, nerve-fibers retain their individuality, and never become blended with adjoining fibers.

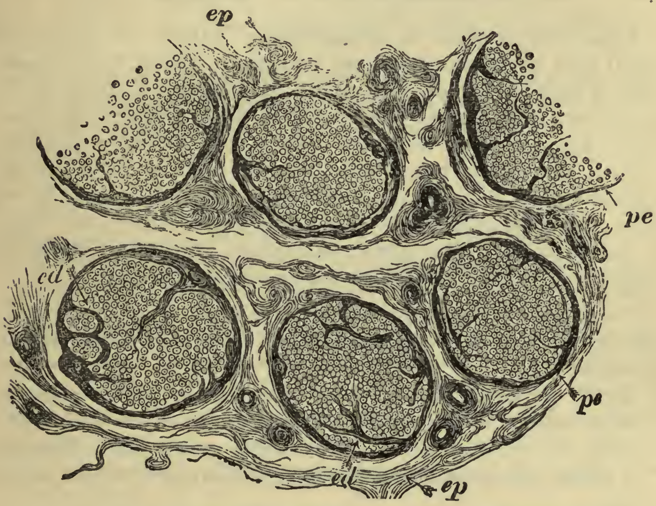


FIG. 8.—TRANSVERSE SECTION OF A NERVE (MEDIAN).
ep. Epineurium. *pe.* Perineurium. *ed.* Endoneurium.

As nerves pass from their origin to their peripheral terminations, they give off a number of branches, each of which becomes invested with a lamellated sheath—an offshoot from that investing the parent trunk. This division of nerve bundles and sheath continues throughout all the branches down to the ultimate nerve-fibers, each of which is surrounded by a sheath of its own, consisting of a single layer of endothelial cells. This delicate transparent membrane, the sheath of Henle, is separated from the nerve-fiber by a considerable space, in which is contained lymph destined for the nutrition of the fiber. Near their ultimate terminations the nerve-fibers themselves undergo division, so that a single fiber may give origin to a number of branches, each of which contains a portion of the parent axis-cylinder and myelin.

CLASSIFICATION OF NERVES.

Nerves are channels of communication between the brain and spinal cord, on the one hand, and the muscles, glands, blood-vessels, skin, mucous membrane, viscera, etc., on the other. Some of the nerve-fibers serve for the transmission of nerve energy or nerve impulses from the brain and spinal cord to certain peripheral organs, and so increase or retard their activities; others serve for the transmission of nerve energy from certain peripheral organs to the brain and spinal cord, which gives rise to sensations or other modes of nerve activity. The former are termed *efferent* or *centrifugal* nerves; the latter are termed *afferent* or *centripetal* nerves.

The **efferent nerves** may be classified, in accordance with the characteristic form of activity to which they give rise, into several groups, as follows:

1. *Muscle* or *motor* nerves, those which convey nerve energy or nerve impulses to muscles and give rise to muscular contraction.
2. *Gland* or *secretory* nerves, those which convey nerve impulses to glands, and cause the formation of the secretion peculiar to the gland.
3. *Vascular* or *vaso-motor* nerves, those which convey nerve impulses to blood-vessels, and cause, either by stimulation or inhibition of the mechanism of their walls, a contraction (vaso-constrictors) or dilatation (vaso-dilatators) of the vessel.
4. *Inhibitor* nerves, those conveying nerve impulses that cause a slowing or complete cessation of the rhythmic action of organs.
5. *Accelerator* nerves, those conveying impulses that cause an increase in the rhythmic action of certain organs.

The **afferent nerves** may also be classified, in accordance with the character of the sensations or other modes of nerve activity to which they give rise, into several groups, as follows:

1. *Sensorifacient* nerves, those conveying nerve impulses that give rise in the brain to conscious sensations. They may be subdivided into—
    - (*a*) Nerves of special sense—*e. g.*, olfactory, optic, auditory, gustatory, tactile, thermal, sensory, muscle—those which give rise to olfactory, optic, auditory, gustatory, tactile, thermic, painful, and muscle sensations.
    - (*b*) Nerves of general sense—*e. g.*, the visceral afferent nerves—those which give rise normally to vague and scarcely perceptible sensations, such as the general sensations of well-being or discomfort, hunger, thirst, fatigue, sex, want of air, etc.
2. *Reflex* nerves, those which convey nerve impulses to the nerve centers and cause a discharge and transmission of nerve impulses outward through efferent nerves to muscles, glands, or blood-vessels, and thus influence their activity. It is quite probable that one and the same nerve may subserve both sensational and reflex action, owing to the collateral branches which are given off from the posterior roots as they ascend the posterior column of the cord.
3. *Inhibitor* nerves, those which are capable reflexly of retarding or inhibiting the activity of either nerve centers or peripheral organs.

The Terminal Endings of Nerves.—The *efferent* nerves, as they approach their ultimate terminations, lose both the neurilemma and medullary sheath. The axis-cylinder then divides into a number of tufts or branches, which become directly and intimately connected with the tissue cells. The particular mode of termination varies in different situations. These terminations are generally spoken of as "end organs."

In the skeletal muscles the nerve-fiber loses both neurilemma and myelin sheath at the point where it comes into contact with the muscle-fiber. After penetrating the sarcolemma, the axis-cylinder breaks up into small branches with bulbous extremities, forming the so-called "motor plate," which rests directly on a disc of granular material containing oval, vesicular nuclei. Each muscle-fiber possesses an individual end-plate.

In the visceral muscles the terminal nerve-fibers form a plexus around the muscle-fibers, and become organically connected with them. In the glands the nerve fibers have been traced directly to their secreting cells. The exact mode of their termination and connection with the cells has not been clearly determined.

The *afferent* nerves, as they approach their peripheral terminations, become connected in like manner with end organs, which, in some instances, are extremely complex, such as those found in the eye (retina), the internal ear, the nose, and the tongue. (A consideration of these end organs will be found in the chapters devoted to the organs of which they form a part.) The end organs of the skin and mucous membranes present a variety of forms, and may be classified as follows:

1. Free endings in the epithelium of the skin, mucous membrane, and cornea.
2. Tactile cells of Merkel in the epidermis.
3. Tactile corpuscles in the papillæ of the true skin.
4. Pacinian corpuscles found attached to the nerves of the hands and feet, to the intercostal nerves, and to nerves in other situations.
5. End bulbs of Krause in the conjunctiva, penis, clitoris, etc.

The **end organs** of the afferent nerves are specialized, highly irritable structures placed between the nerve-fibers and the surface of the body. They are especially adapted for the reception of those external forces technically known as stimuli, and for the liberation of energy capable of exciting the nerve-fiber to activity.

Relation of Spinal Nerves to the Spinal Cord.—The nerves in connection with the spinal cord are thirty-one in number, on each side and have two roots of origin, an anterior and a posterior, which arise from the anterior and posterior surfaces of the cord respectively. They are more properly termed *ventral* and *dorsal* roots. The dorsal roots present, near their entrance into the cord, an enlargement termed a ganglion. Beyond the spinal canal these two roots unite to form the ordinary spinal nerve. Some of the nerves in connection with the base of the brain also present a ganglionic enlargement, and may, therefore, be regarded physiologically as dorsal nerves, while others may be regarded as ventral nerves.

Experimentally, it has been determined that the anterior or ventral roots contain all the *efferent* fibers, the posterior or dorsal roots all the *afferent* fibers. The proofs in support of this view are as follows:

Stimulation of the ventral roots produces:

1. Convulsive movements of muscles.
2. The formation of a secretion in glands.
3. Changes in the caliber of blood-vessels.

4. Inhibition of the rhythmic activity of certain organs.

Divisions of these roots is followed by:

1. Loss of muscular movement (paralysis of motion).
2. Cessation of secretion.
3. Cessation of vascular changes.

Stimulation of the dorsal roots causes:

1. Reflex activities.
2. Conscious sensations.
3. Inhibition of the rhythmic activity of certain organs.

Division of these roots is followed by:

1. Loss of reflex activities, and
2. Loss of sensation in all parts to which they are distributed.

The ventral roots are, therefore, efferent in function, transmitting nerve impulses from the nerve centers to the periphery. The dorsal roots are afferent in function, transmitting nerve impulses from the general periphery to the nerve centers.

Development and Nutrition of Nerves.—The **efferent nerve-fibers,** which constitute some of the cranial nerves and all the ventral roots of the spinal nerves, have their origin in cells located in the gray matter beneath the aqueduct of Sylvius, beneath the floor of the fourth ventricle and in the anterior horns of the gray matter of the spinal cord. These cells are the modified descendants of independent, oval, pear-shaped cells—the neuroblasts—which migrate from the medullary tube. As they approach the surface of the cord their axons are directed toward the ventral surface, which eventually they pierce. Emerging from the cord, the axons continue to grow, and become invested with the myelin sheath and neurilemma, thus constituting the ventral roots.

The **afferent nerve-fibers,** which constitute some of the cranial nerves and all the dorsal roots of the spinal nerves, develop outside of the central nervous system and only subsequently become connected with it. (See Fig. 9.) At the time of the closure of the medullary tube a band or ridge of epithelial tissue develops near the dorsal surface, which, becoming segmented, moves outward and forms the rudimentary spinal ganglia. The cells in this situation develop two axons, one from each end of the cell, which pass in opposite directions, one toward the spinal cord, the other toward the periphery. In the adult condition the two axons shift their position, unite, and form a T-shaped process, after which a division into two branches again takes place. In the ganglia of all the sensoricranial and sensorispinal nerves the cells have this histologic peculiarity.

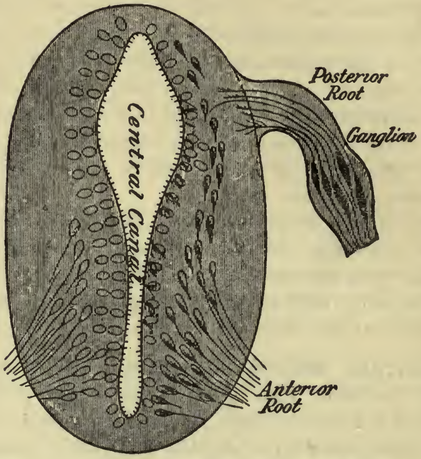


FIG 9.—DIAGRAM SHOWING THE MODE OF ORIGIN OF THE VENTRAL AND DORSAL ROOTS.

Nerve Degeneration.—If any one of the cranial or spinal nerves be divided in any portion of its course, the part in connection with the periphery in a short time exhibits certain structural changes, to which the term degeneration is applied. The portion in connection with the brain or cord retains its normal condition. The degenerative process begins simultaneously throughout the entire course of the nerve, and consists in a disintegration and reduction of the medulla and axis-cylinder into nuclei, drops of myelin, and fat, which in time disappear through absorption, leaving the neurilemma intact. Coincident with these structural changes there is a progressive alteration and diminution in the excitability of the nerve. Inasmuch as the central portion of the nerve, which retains its connection with the nerve-cell, remains histologically normal, it has been assumed that the nerve-cells exert over the entire course of the nerve-fibers a nutritive or a trophic influence. This idea has been greatly strengthened since the discovery that the axis-cylinder, or the axon, has its origin in and is a direct outgrowth of the cell. When separated from the parent cell, the fiber appears to be incapable of itself of maintaining its nutrition.

The relation of the nerve-cells to the nerve-fibers, in reference to their nutrition, is demonstrated by the results which follow section of the ventral and dorsal roots of the spinal nerves. If the anterior root alone be divided, the degenerative process is confined to the peripheral portion, the central portion remaining normal. If the posterior root be divided on the peripheral side of the ganglion, degeneration takes place only in the peripheral portion of the nerve. If the root be divided between the ganglion and the cord, degeneration takes place only in the central portion of the root. From these facts it is evident that the trophic centers for the ventral and dorsal roots lie in the spinal cord and spinal nerve ganglia, respectively, or, in other words, in the cells of which they are an integral part. The structural changes which nerves undergo after separation from their centers are degenerative in character, and the process is usually spoken of, after its discoverer, as the *Wallerian degeneration.*

When the degeneration of the efferent nerves is completed, the structures to which they are distributed, especially the muscles, undergo an atrophic or fatty degeneration, with a change or loss of their irritability. This is, apparently, not to be attributed merely to inactivity, but rather to a loss of nerve influences, inasmuch as inactivity merely leads to atrophy and not to degeneration.

Reactions of Degeneration.—In consequence of the degeneration and changes in irritability which occur in nerves when separated from their centers and in muscles when separated from their related nerves, either experimentally or as the result of disease, the response of these structures to the induced and the make-and-break of the constant currents differs from that observed in the physiologic condition. The facts observed under the application of these two forms of electricity are of the greatest importance in the diagnosis and therapeutics of the precedent lesions. The principal difference of behavior is observed in the muscles, which exhibit a diminished or abolished excitability to the induced current, while at the same time manifesting an increased excitability to the constant current; so much so is this the case that a closing contraction is just as likely to occur at the positive as at the negative pole. This peculiarity of the muscle response is termed the *reaction of degeneration.* The synchronous diminished excitability of the nerves is the same for either current. The term "partial reaction of degeneration" is used when there is a normal reaction of the nerves, with the degenerative reaction of the muscles. This condition is observed in progressive muscular atrophy.

Reflex Action.—Inasmuch as many of the muscle movements of the body, as well as the formation and discharge of secretions from glands, variations in the caliber of blood-vessels, inhibition and acceleration in the activity of various organs, are the result of stimulations of the terminal organs of afferent nerves, they are termed, for convenience, reflex actions, and, as they take place independently of the brain or of volitional impulses, they are also termed involuntary actions. As many of the processes to be described in succeeding chapters are of this character, requiring for their performance the coöperation of several organs and tissues associated through the intermediation of the nervous system, it seems advisable to consider briefly, in this connection, the parts involved in a reflex action, as well as their mode of action. As shown in figure 10, the necessary structures are as follows:

1. A sentient surface, skin, mucous membrane, sense organ, etc.
2 An afferent nerve.
3. An emissive cell, from which arises
4. An efferent nerve, distributed to a responsive organ, as
5. Muscle, gland, blood-vessel, etc.

Such a combination of structures constitutes a reflex mechanism or arc the nerve portion of which is composed of but two neurons—an afferent and an efferent. An arc of this simplicity would of necessity subserve but a simple movement. The majority of reflex activities, however, are extremely complex, and involve the coöperation and coördination of a number of structures frequently situated at distances more or less remote from one another. This implies that a number of neurons are associated in function. The afferent neurons are brought into relation with the dendrites of the efferent neurons by the end tufts of the collateral branches, which may extend for some distance up and down the cord before passing into the various segments.

For the excitation of a reflex action it is essential that the stimulus applied to the sentient surface be of an intensity sufficient to develop in the terminals of the afferent nerve a series of nerve impulses, which, raveling inward, will be distributed to and received by the dendrites of the emissive or motor cell. With the reception of these impulses there is apparently a disturbance of the equilibrium of its molecules, a liberation of energy, and, in consequence, a transmission outward of impulses through the efferent nerve to muscle, gland, or blood-vessel, separately or collectively, with the production of muscular contraction, glandular secretion, vascular dilatation or contraction, etc. The reflex actions take place, for the most part, through the spinal cord and medulla oblongata, which, in virtue of their contained centers, coördinate the various organs and tissues concerned in the performance of the organic functions. The movements of mastication; the secretion of saliva; the muscular, glandular, and vascular phenomena of gastric and intestinal digestion; the vascular and respiratory movements; the mechanism of micturition, etc., are illustrations of reflex activity.

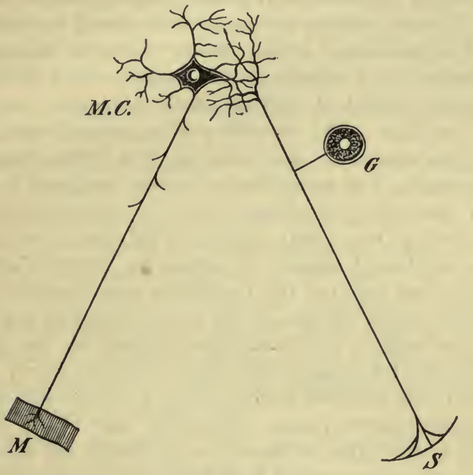


FIG 10.—DIAGRAM ILLUSTRATING REFLEX ACTION.—(*Kirke.*)

S. Sentient surface from which proceeds the afferent nerve. *M. C.* Motor or emissive cell giving origin to efferent nerve which terminates in *M.* *M.* Motor organ. *G.* Ganglion cell on afferent nerve.

PHYSIOLOGIC PROPERTIES OF NERVES.

Nerve Irritability or Excitability and Conductivity.—These terms are employed to express that condition of a nerve which enables it to develop and to conduct nerve impulses from the center to the periphery, from the periphery to the center, in response to the action of stimuli. A nerve is said to be excitable or irritable as long as it possesses these capabilities or properties. For the manifestation of these properties the nerve must retain a state of physical and chemic integrity; it must undergo no change in structure or chemic composition. The irritability of an *efferent* nerve is demonstrated by the contraction of a muscle, by the secretion of a gland, or by a change in the caliber of a blood-vessel, whenever a corresponding nerve is stimulated. The irritability of an *efferent* nerve is demonstrated by the production of a sensation or a reflex action whenever it is stimulated. The irritability of nerves continues for a certain period of time after separation from the nerve centers and even after the death of the animal, varying in different classes of animals. In the warm-blooded animals, in which the nutritive changes take place with great rapidity, the irritability soon disappears—a result due to disintegrative changes in the nerve, caused by the withdrawal of the blood-supply. In cold-blooded animals, on the contrary, in which the nutritive changes take place relatively slowly, the irritability lasts, under favorable conditions, for a considerable time. Other tissues besides nerves possess irritability, that is, the property of responding to the action of stimuli—*e. g.*, glands and muscles, which respond by the production of a secretion or a contraction.

Independence of Tissue Irritability.—The irritability of nerves is distinct and independent of the irritability of muscles and glands, as shown by the fact that it persists in each a variable length of time after their histologic connections have been impaired or destroyed by the introduction of various chemic agents into the circulation. Curara, for example, induces a state of complete paralysis by modifying or depressing the conductivity of the end organs of the nerves just where they come in contact with the muscles without impairing the irritability of either nerve trunks or muscles. Atropin induces complete suspension of glandular activity by impairing the terminal organs of the secretor nerves just where they come into relation with the gland-cells, without destroying the irritability of either gland or nerve.

Stimuli of Nerves.—Nerves do not possess the power of spontaneously generating and propagating nerve impulses; they can be aroused to activity only by the action of an extraneural stimulus. In the living condition the stimuli capable of throwing the nerve into an active condition act for the most part on either the central or peripheral end of the nerve. In the case of motor nerves the stimulus to the excitation, originating in some molecular disturbance in the nerve-cells, acts upon the nerve-fibers in connection with them. In the case of sensor or afferent nerves the stimuli act upon the peculiar end organs with which the sensor nerves are in connection, which in turn excite the nerve-fibers. Experimentally, it can be demonstated that nerves can be excited by a sufficiently powerful stimulus applied in any part of their extent.

Nerves respond to stimulation according to their habitual function; thus, stimulation of a sensor nerve, if sufficiently strong, results in the sensation of pain; of the optic nerve, in the sensation of light; of a motor nerve, in contraction of the muscle to which it is distributed; of a secretor nerve, in the activity of the related gland, etc. It is, therefore, evident that peculiarity of nerve function depends neither upon any special construction or activity of the nerve itself, nor upon the nature of the stimulus, but entirely upon the peculiarities of its central and peripheral end organs.

Nerve stimuli may be divided into—

1. *General stimuli,* comprising those agents which are capable of exciting a nerve in any part of its course.
2. *Special stimuli,* comprising those agents which act upon nerves only through the intermediation of the end organs.

General stimuli:

1. Mechanical: as from a blow, pressure, tension, puncture, etc.
2. Thermal: heating a nerve at first increases and then decreases its excitability.
3. Chemic: sensor nerves respond somewhat less promptly than motor nerves to this form of irritation.
4. Electric: either the constant or interrupted current.
5. The normal physiologic stimulus:
    - (*a*) Centrifugal or efferent, if proceeding from the center toward the periphery.
    - (*b*) Centripetal or afferent, if in the reverse direction.

Special stimuli:

1. Light or ethereal vibrations acting upon the end organs of the optic nerve in the retina.
2. Sound or atmospheric undulations acting upon the end organs of the auditory nerve.
3. Heat or vibrations of the air upon the end organs in the skin.
4. Chemic agencies acting upon the end organs of the olfactory and gustatory nerves.

Nature of the Nerve Impulse.—As to the nature of the nerve impulse generated by any of the foregoing stimuli either general or special, but little is known. It has been supposed to partake of the nature of a molecular disturbance, a combination of physical and chemical processes attended by the liberation of energy, which propagates itself from molecule to molecule. Judging from the deflections of the galvanometer needle it is probable that when the nerve impulse makes its appearance at any given point it is at first feeble but soon reaches a maximum development after which it speedily declines and disappears. It may, therefore, be graphically represented as a wave-like movement with a definite length and time duration. Under strictly physiological conditions the nerve impulse passes in one direction only; in efferent nerves from the center to the periphery, in afferent nerves from the periphery to the center. Experimentally, however, it can be demonstrated that when a nerve impulse is aroused in the course of a nerve by an adequate stimulus it travels equally well in both directions from the point of stimulation. When once started the impulse is confined to the single fiber and does not diffuse itself to fibers adjacent to it in the same nerve trunk.

Rapidity of Transmission of Nerve Force.—The passage of a nervous impulse, either from the brain to the periphery or in the reverse direction, requires an appreciable period of time. The velocity with which the impulse travels in human sensor nerves has been estimated at about 190 feet a second, and for motor nerves at from 100 to 200 feet a second. The rate of movement is, however, somewhat modified by temperature, cold lessening and heat increasing the rapidity; it is also modified by electric conditions, by the action of drugs, the strength of the stimulus, etc. The rate of transmission through the spinal cord is considerably slower than in nerves, the average velocity for voluntary motor impulses being only 33 feet a second, for sensitive impressions 40 feet, and for tactile impressions 140 feet a second.

Electric Currents in Muscles and Nerves.—If a muscle or nerve be divided and non-polarizable electrodes be placed upon the natural longitudinal surface at the equator, and upon the transverse section, electric currents are observed with the aid of a delicate galvanometer. The direction of the current is always from the positive equatorial surface to the negative transverse surface. The strength of the current increases or diminishes according as the positive electrode is moved toward or from the equator. When the electrodes are placed on the two transverse ends of a nerve, an axial current will be observed the direction of which is opposite to that of the normal impulse of the nerve.

The *electromotive force* of the strongest nerve-current has been estimated to be equal to the 0.026 of a Daniell battery; the force of the current of the frog muscle, about 0.05 to 0.08 of a Daniell.

Negative Variation of Currents in Muscles and Nerves.—If a muscle or nerve be thrown into a condition of tetanus, it will be observed that the currents undergo a diminution of negative variation, a change which passes along the nerve in the form of a wave and with a velocity equal to the rate of transmission of the nerve impulse. The wave-length of a single negative variation has been estimated to be eighteen millimeters, the period of its duration being from 0.0005 to 0.0008 of a second.

It is asserted by Hermann that perfectly fresh, uninjured muscles and nerves are devoid of currents, and that the currents observed are the result of molecular death at the point of section, this point becoming negative to the equatorial point. He applies the term "action currents" to the currents obtained when a muscle is thrown into a state of activity.

Electrotonus.—The passage of a direct galvanic current through a portion of a nerve excites in the parts beyond the electrodes a condition of electric tension, or *electrotonus,* during which the *excitability* of the nerve is *decreased* near the anode or positive pole, and *increased* near the cathode or negative pole; the increase of excitability in the *catelectrotonic area*—that nearest the muscle—being manifested by a more marked contraction of the muscle than the normal when the nerve is irritated in this region. The passage of an *inverse* galvanic current excites the same condition of electrotonus;

the *diminution* of excitability near the anode, the *anelectrotonic*.—that now nearest the muscle,—being manifested by a less marked contraction than the normal when the nerve is stimulated in this region. Similar conditions exist within the electrodes. Between the electrodes is a neutral point, where the catelectrotonic area merges into the anelectrotonic area. If the current be a strong one, the neutral point approaches the cathode; if weak, it approaches the anode.

When a nerve impulse passes along a nerve, the only appreciable effect is a change in its electric condition, there being no change in its temperature, chemic composition, or physical condition. The natural nerve-currents, which are always present in a living nerve as a result of its nutritive activity, in great part disappear during the passage of an impulse, undergoing a *negative variation.*

Law of Contraction.—If a *feeble* galvanic current be applied to a recent and excitable nerve, contraction is produced in the muscles only upon the *making* of the circuit with both the direct and inverse currents.

If the current be *moderate* in intensity, the contraction is produced in the muscle, both upon the *making* and *breaking* of the circuit, with both the direct and inverse currents.

If the current be *intense,* contraction is produced only when the circuit is *made* with the direct current, and only when it is *broken* with the inverse current.

FOODS AND DIETETICS.

During the functional activity of every organ and tissue of the body the living material of which it is composed—the *protoplasm*—undergoes more or less disintegration. Through a series of descending chemic stages it is reduced to a number of simpler compounds, which are of no further value to the body, and which are in consequence eliminated by the various eliminating or excretory organs—the lungs, kidneys, skin, liver. Among these compounds the more important are carbon dioxid, urea, and uric acid. Many other compounds, inorganic as well as organic, are also eliminated in the water discharged from the body, in which they are held in solution.

Coincident with this disintegration of the tissues there is an evolution or disengagement of energy, particularly in the form of heat.

In order that the tissues may regain their normal composition and thus be enabled to continue in the performance of their functions, they must be supplied with the same nutritive materials of which their protoplasm originally consisted—viz., water, inorganic salts, proteids, sugar, fat. These materials are furnished by the blood during its passage through the capillary blood-vessels. The blood is a reservoir of nutritive material in a condition to be absorbed, organized, and transformed into new living tissue.

Inasmuch as the loss of material from the body daily, which is very great, is compensated for under other forms by the blood, it is evident that this fluid would rapidly diminish in volume were it not restored by the introduction of new and corresponding materials. As soon as the blood volume falls to a certain point, the sensations of hunger and thirst arise, which in a short time lead to the necessity of taking food.

In addition to the direct appropriation of food by the tissues it is highly probable that an indefinite amount undergoes oxidation and disintegration without ever becoming an integral part of the tissues, and thus directly contributes to the production of heat.

Inanition or Starvation.—If these nutritive principles be not supplied in sufficient quantity, or if they are withheld entirely, a condition of physiologic decay is established, to which the term inanition or starvation is applied. The phenomena which characterize this pathologic process are as follows—viz., hunger, intense thirst, gastric and intestinal uneasiness and pain, muscle weakness and emaciation, a diminution in the quantity of carbon dioxid exhaled, a lessening in the amount of urine and its constituents excreted, a diminution in the volume of the blood, an exhalation of a fetid odor from the body, vertigo, stupor, delirium, and at times convulsions, a fall of bodily temperature, and, finally, death from exhaustion.

During starvation the loss of different tissues, before death occurs, averages $\frac{4}{10}$, or 40 per cent., of their weight.

Those tissues which lose *more* than *40 per cent.* are: Fat, 93.3; blood, 75; spleen, 71.4; pancreas, 64.1; liver, 52; heart, 44.8; intestines, 42.4; muscle, 42.3. Those which lose *less* than *40 per cent.* are: The muscular coat of the stomach, 39.7; pharynx and esophagus, 34.2; skin, 33.3; kidneys, 31.9; respiratory apparatus, 22.2; bones, 16.7; eyes, 10; nervous system, 1.9.

The *fat* entirely disappears, with the exception of a small quantity which remains in the posterior portion of the orbits and around the kidneys. The *blood* diminishes in volume and loses its nutritive properties. The *muscles* undergo a marked diminution in volume and become soft and flabby. The *nervous system* is last to suffer, not more than two per cent., disappearing before death occurs.

The *appearances* presented by the body after death from starvation are those of anemia and great emaciation; almost total absence of fat; bloodlessness; a diminution in the volume of the organs; an empty condition of the stomach and bowels, the coats of which are thin and transparent. There is a marked disposition of the body to undergo decomposition, giving rise to a very fetid odor.

The *duration of life* after a complete deprivation of food varies from eight to thirteen days, though life can be maintained much longer if a quantity of water be obtained. The water is more essential under these circumstances than the solid matters, which can be supplied by the organism itself.

The different alimentary or nutritive principles which are appropriated by the tissues, and which are contained within the various articles of food, belong to both the organic and inorganic groups and chemic compounds, and may be classified according to their composition as follows:

CLASSIFICATION OF ALIMENTARY PRINCIPLES.

1. **Proteid Group.—Nitrogenized, C, O, H, N, S, P.**

Principle.	*Where Found.*
Myosin	Flesh of animals.
Vitellin, albumin	Yolk of egg, white of egg.
Fibrin, globulin	Blood contained in meat.
Casein	Milk, cheese.
Gluten	Grain of wheat and other cereals.
Vegetable albumin	Soft, growing vegetables.
Legumin	Peas, beans, lentils, etc.
Gelatin	Bones.

2. **Oleaginous Group.—C, O, H.**

Animal fats and oils	Found in the adipose tissue of animals, seeds, grains, nuts, fruits, and other vegetable tissues.
Stearin, olein	
Palmitin, fatty acids	

3. **Carbohydrate Group.—C, O, H.**

Saccharose, or *cane-sugar*	Sugar-cane.
Dextrose, or *glucose*	Fruits.
Levulose, or *fruit-sugar*	
Lactose, or *milk-sugar*	Milk.
Maltose	Malt, malt foods.
Starch	Cereals, tuberous roots, and leguminous plants.
Glycogen	Liver, muscles.

4. **Inorganic Group.**—Water; sodium and potassium chlorids; sodium calcium, magnesium, and potassium phosphates; calcium carbonate; and iron.

5. **Vegetable Acid Group.**—Malic, citric, tartaric, and other acids, found principally in fruits.

6. **Accessory Foods.**—Tea, coffee, alcohol, cocoa, etc.

The *proteid principles* of the food, after undergoing digestion and conversion into peptones, are absorbed and transformed into the form of proteids characteristic of the blood plasma and the lymph. Of the proteids thus brought into relation with the living protoplasm, a small percentage only is utilized in the repair of its substance. This is known as *tissue proteid.* A large percentage circulating among and permeating the tissues is acted upon by them directly, and reduced to simpler compounds without ever becoming a part of the tissue itself. This is known as *circulating proteid.* In the process of tissue metabolism all the proteids suffer disintegration, and give rise to the production of some carbon-holding compound, probably fat, and some nitrogen-holding compounds which eventually produce urea. The intermediate stages are possibly represented by glycin, creatin, uric acid, etc. An excess of proteids in the food is followed by their decomposition, by the pancreatic juice, into leucin and tyrosin, which, by the agency of the liver, are converted into urea. The disintegration of the proteids is attended by the disengagement of heat: they thus contribute to the energy of the body.

The *oleaginous principles,* after digestion, are absorbed into the blood, from which they rapidly disappear. It is probable that a portion of the fat enters directly into the composition of living protoplasm, out of which it again emerges at some subsequent stage in the form of small drops which make their appearance in the protoplasmic cells of the connective areolar tissue, thus giving rise to the adipose tissue. Another portion probably undergoes direct oxidation.

The *carbohydrate principles,* after digestion, are absorbed as dextrose and temporarily stored up in the liver as glycogen. The intermediate stages which sugar passes through and the combinations into which it enters between its absorption and its elimination are but imperfectly understood. That it contributes to the accumulation of fat is probable, though it is doubtful if it is ever converted into fat. A large percentage of the sugar absorbed is at once oxidized. The reduction of fat and sugar to carbon dioxid and water, under which forms they are eliminated from the body, is accompanied by a disengagement of a large quantity of heat.

Water is present in all the fluids and solids of the body. It promotes the absorption of new material from the alimentary canal; it holds the various ingredients of the blood, lymph, and other fluids in solution; it hastens the absorption of waste products from the tissues, and promotes their speedy elimination from the body.

Sodium chlorid is present in all parts of the body to the extent of 110 gm. The average amount eliminated daily is 15 gm. Its necessity as an article of diet is at once apparent. Taken as a condiment, it imparts sapidity to the food, excites the flow of the digestive fluids, promotes the absorption and assimilation of the albumins, influences the passage of nutritive material through animal membranes, and furnishes the chlorin for the free hydrochloric acid of the gastric juice. In some unknown way it favorably promotes the activity of the general nutritive process.

The *potassium salts* are also essential to the normal activity of the nutritive process. When deprived of these salts, animals become weak and emaciated. When given in small doses, they increase the force of the heart-beat, raise the arterial pressure, and thus increase the action of the circulation of the blood.

The *calcium phosphate and carbonate* are utilized in imparting solidity to the tissues, more especially the bones and teeth. Many articles of food contain these salts in quantities sufficient to restore the amount lost daily.

The *vegetable acids* increase the secretions of the alimentary canal, and are apt, in large amounts, to produce flatulence and diarrhea. After entering into combination with bases to form salts, they stimulate the action of the kidneys and promote a greater elimination of all the urinary constituents. In some unknown way they influence nutrition; when deprived of these acids, the individual becomes scorbutic.

The *accessory foods,* coffee and tea, when taken in moderation, overcome the sense of fatigue and mental unrest consequent on excessive physical and mental exertion. Coffee increases the action of the intestinal glands and acts as a laxative. After absorption, its active principle, *caffein,* stimulates the action of the heart, raises the arterial pressure, and excites the action of the brain. Tea acts as an astringent, owing to the tannic acid it contains. One effect of the tannic acid is to coagulate the digestive ferments and to interfere with the activity of the digestive process.

Alcohol, when introduced into the system in *small quantities,* undergoes oxidation and contributes to the production of force, and is thus far a food. It excites the gastric glands to increased secretion, improves the digestion, accelerates the action of the heart, and stimulates the activities of the nerve centers. In zymotic diseases, and in all cases of depression of the vital powers, it is most useful as a restorative agent. When taken in *excessive quantities,* it is eliminated by the lungs and kidneys. The metamorphosis of the tissue is retarded, the elimination of urea and carbonic acid is lessened, the temperature is lowered, the muscular powers are impaired, and the resistance to depressing external influences is diminished. When taken throughout a long period of time, alcohol impairs digestion, produces gastric catarrh, and disorders the secreting power of the hepatic cells. It also diminishes the muscular power and destroys the structure and composition of the cells of the brain and spinal cord. The connective tissue of the body increases in amount, and, subsequently contracting, gives rise to sclerosis.

A **proper combination** of various alimentary principles is essential for healthy nutrition, no one class being capable of maintaining life for any definite length of time.

The *albuminous food* in excess promotes the arthritic diathesis, manifesting itself as gout, gravel, etc.

The *oleaginous food* in excess gives rise to the bilious diathesis, while a deficiency of it promotes the scrofulous.

The *farinaceous food* when long continued in excess, favors the rheumatic diathesis by the development of lactic acid.

The **quantities** of the different nutritive materials which are required daily for the growth and repair of the tissues and for the evolution of heat have been variously estimated by different observers. The following table shows the average diet scale of Vierordt, and the amount of waste products to which it would give rise:

COMPARISON OF THE INGESTA AND EGESTA.

Ingesta.			*Egesta.*		
Proteids . . .	120	grams.	Urea	40	grams.
Fat	90	“	Inorganic salts.	32	“
Starch . . .	330	“	Feces	104	“
Inorganic salts.	32	“	Carbon dioxid .	800	“
Water . . .	2,800	“	Water . . .	3,096	“
Oxygen . . .	700	“	Total . .	4,072	“
Total . .	4,072	“			

Other estimates as to the amount of the organic substances required daily are as follows:

	Ranke.	*Voit.*	*Atwater.*	*Moleschott.*
Proteid . .	100	118	125	130 grams.
Fat . . .	100	50	125	84 “
Starch . .	240	500	400	404 “

The Energy of the Animal Body.—The food consumed daily not only repairs the loss of material from the body, but also furnishes the energy to replace that which is expended daily in the shape of heat and motion. All the energy of the body can be traced to the chemic changes going on in the tissues, and more particularly to those changes involved in the oxidation of the foods.

The amount of heat yielded by any given food principle can be determined by burning it to carbon dioxid and water, and ascertaining the extent to which it will, when so liberated, raise the temperature of a given volume of water. This amount of heat may be expressed in calories. A calorie is the amount of heat required to raise the temperature of *one kilogram* of water *one degree* Centigrade.

The following estimates give, approximately, the number of calories produced when the food is reduced within the body to urea, carbon dioxid, and water:

1	gram of	proteid	yields	4,124	kilogram	calories.
1	“	fat	“	9,353	“	“
1	“	starch	“	4,116	“	“

The total number of kilogram calories yielded by any given diet scale can be readily determined by multiplying the preceding factors by the quantities of material consumed. The diet scale of Ranke, for example, yields the following amount:

100	grams of	proteid	yield	412.4	calories.
100	"	fat	"	935.3	"
240	"	starch	"	987.8	"
Total				2,335.5	"

It has also been determined experimentally that one gram of proteid, one gram of fat, and one gram of starch, when completely oxidized, will yield energy sufficient to perform, 1,850, 3,841, and 1,567 kilogrammeters of work, respectively. A kilogrammeter of work is one kilogram raised one meter high.

The total energy of the Ranke diet scale can be easily calculated —*e. g.*,

100	grams of	proteid	yield	185,000	kilogrammeters.
100	"	fat	"	384,100	"
240	"	starch	"	397,680	"
Total				966,780	"

It will be thus seen that the food consumed daily yields 2,335 *kilogram calories,* which can be translated into its mechanical equivalent, 966,780 kilogrammeters of work.

The **amount of food** required in twenty-four hours is estimated from the total quantity of carbon and nitrogen excreted from the body in twenty-four hours, these two elements representing the waste or destruction of the carbonaceous and nitrogenized compounds. It has been determined by experimentation that about 4,600 grains of carbon and about 300 grains of nitrogen are eliminated from the body daily, the ratio being about 15 to 1. That the body may be kept in its normal condition, a proper proportion of carbonaceous (bread) to nitrogenized (meat) food should be observed in the diet.

The method of determining the proper amounts of both kinds of food is as follows:

1,000 grs. of bread (2 oz.) contain 300 grs. C. and 10 grs. N.

To obtain the requisite amount of nitrogen from bread, 30,000 grains, or about four pounds, containing 9,000 grains of carbon and

300 of nitrogen, would have to be consumed. On such a diet there would be a large excess of carbon, which would be undesirable. On a meat diet the reverse obtains:

1,000 grs. of meat (2 oz.) contain 100 grs. C and 30 grs. N.

To obtain the requisite amount of carbon from meat, 45,000 grains, or about 6½ pounds, containing 4,500 grains of carbon and 1,350 grains of nitrogen would have to be consumed. Under such circumstances there would arise an excess of nitrogen in the system, which would be equally undesirable and injurious. By combining these two articles, however, in proper proportion, the requisite amounts of carbon and nitrogen can be obtained without any excess of either—*e. g.:*

2 pounds	of bread	contain	4,630 grs. C	and	154 grs. N.
¾ "	meat	"	463	"	154 "
			5,093 C.		308 N.

The amount of carbon and nitrogen necessary to compensate for the loss to the system daily would be contained in the foregoing amount of food. As about 3½ ounces of oil or butter are consumed daily, the quantity of bread can be reduced to 19 ounces. In the quantities of bread and meat just mentioned there are 4.2 ounces albumin, 9.3 sugar and starch.

The **alimentary principles** are not introduced into the body as such, but are combined in proper proportions to form compound substances, termed *foods,—e. g.,* bread, milk, eggs, meat, etc.,—the nutritive value of each depending upon the extent to which these principles exist.

The following tables show the average composition of various articles of food:

COMPOSITION OF ANIMAL FOODS.

In 100 Parts.	Beef.	Veal.	Mutton.	Pork.	Fowl.	Fish.
Water, ...	76.25	77.82	75.59	72.57	70.80	79.30
Proteid, ...	20.24	19.86	17.11	19.31	22.70	18.30
Fat, ...	1.68	0.82	5.47	5.82	4.10	0.70
Carbohydrates, .	0.50	0.80	0.60	0.60	1.20	0.90
Salts, ...	1.38	0.70	1.23	1.70	1.20	0.80

COMPOSITION OF VEGETABLE FOODS.

In 100 Parts.	Beans.	Peas.	Potatoes	Turnips.	Cabbage.	Asparagus.
Water, ...	13.74	14.99	75.47	89.42	89.97	93.75
Proteid, ...	23.21	22.85	1.95	1.35	1.89	1.79
Fat, ...	2.14	1.79	0.15	0.18	0.20	0.25
Carbohydrates, .	53.67	52.36	20.69	7.36	4.87	2.63
Cellulose, . . .	3.69	5.43	0.76	0.94	1.84	1.04
Salts, ...	3.55	2.58	0.98	0.75	1.23	0.54

COMPOSITION OF CEREAL FOODS.

In 100 Parts.	Wheat.	Rye.	Barley.	Oats.	Corn.	Rice
Water, ...	13.56	12.65	13.77	12.37	13.10	13.12
Proteid, ...	12.35	12.55	11.14	10.41	9.85	7.88
Fat, ...	1.75	1.97	2.16	5.23	4.57	0.85
Carbohydrates, .	67.90	67.95	64.93	57.78	68.42	76.55
Cellulose, . . .	2.63	3.00	5.31	11.19	2.50	0.55
Salts, ...	1.81	1.88	2.69	3.02	1.56	1.05

DIGESTION.

Digestion is a physical and chemic process by which the food introduced into the alimentary canal is liquefied and its nutritive principles are transformed by the digestive fluids into new substances capable of being absorbed into the blood.

The **digestive apparatus** consists of the alimentary canal and its appendages—viz., teeth; salivary, gastric and intestinal glands; liver; and pancreas.

Digestion may be divided into *seven stages:* prehension, mastication, insalivation, deglutition, gastric and intestinal digestion, and defecation.

Prehension, the act of conveying food into the mouth, is accomplished by the hands, lips, and teeth.

MASTICATION.

Mastication is the trituration of the food, and is accomplished by the teeth and lower jaw under the influence of muscular contraction. When thoroughly divided, the food presents a larger surface for the solvent action of the digestive fluids, thus aiding the general process of digestion.

The **teeth** are thirty-two in number, sixteen in each jaw, and divided into four incisors or cutting teeth, two canines, four bicuspids, and six molars or grinding teeth; each tooth consists of a crown covered by enamel, a neck, and a root surrounded by the crusta petrosa and embedded in the alveolar process; a section through a tooth shows that its substance is made of *dentine,* in the center of which is the pulp cavity containing blood-vessels and nerves.

The *lower jaw* is capable of making a downward and an upward, a lateral and an anteroposterior movement, dependent upon the construction of the temporomaxillary articulation.

The jaw is *depressed* by the contraction of the *digastric, geniohyoid, mylohyoid,* and *platysma myoides* muscles; *elevated* by the *temporal, masseter,* and *internal pterygoid* muscles; moved *laterally* by the alternate contraction of the *external pterygoid* muscles; moved *anteriorly* by the *pterygoid,* and *posteriorly* by the united actions of the *geniohyoid, mylohoid,* and posterior fibers of the *temporal* muscles.

The food is kept between the teeth by the *intrinsic* and *extrinsic* muscles of the tongue from within, and the *orbicularis oris* and *buccinator* muscles from without.

The **movements of mastication,** though originating in an effort of the will and under its control, are, for the most part, of an automatic or reflex character, taking place through the medulla oblongata and induced by the presence of food within the mouth. The nerves and nerve-centers involved in this mechanism are shown in the following table:

Nerve Mechanism of Mastication.

Afferent Nerves.	*Efferent Nerves.*
1. Lingual branch of 5th pair.	1. Third branch of 5th pair.
2. Glossopharyngeal.	2. Hypoglossal
	3. Facial.

The impressions made upon the terminal filaments of the afferent nerves are transmitted to the medulla; motor impulses are here generated which are transmitted through motor nerves to the muscles involved in the movements of the lower jaw. The medulla not only generates motor impulses, but coördinates them in such a manner that the movements of mastication may be directed toward the accomplishment of a definite purpose.

INSALIVATION.

Insalivation is the incorporation of the food with the saliva secreted by the *parotid, submaxillary,* and *sublingual glands;* the *parotid* saliva, thin and watery, is poured into the mouth through Steno's duct; the *submaxillary* and *sublingual* salivas, thick and viscid, are poured into the mouth through Wharton's and Bartholin's ducts.

In their minute structure the salivary glands resemble one another. They belong to the racemose variety, and consist of small sacs or vesicles, which are the terminal expansions of the smallest salivary ducts. Each vesicle or *acinus* consists of a basement membrane surrounded by blood-vessels and lined with epithelial cells. In the parotid gland the lining cells are granular and nucleated; in the submaxillary and sublingual glands the cells are large, clear, and contain a quantity of mucigen. During and after secretion very remarkable changes take place in the cells lining the acini, which are in some way connected with the essential constituents of the salivary fluids.

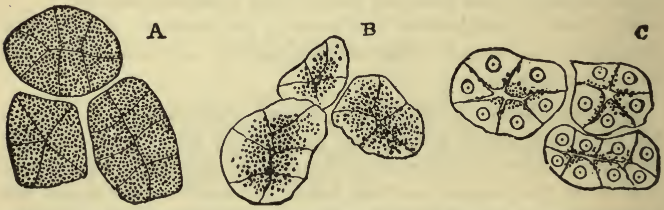


FIG. 11.—CELLS OF THE ALVEOLI OF A SEROUS OR WATERY SALIVARY GLAND.—(*Yeo's "Text-book of Physiology."*)

A. After rest. B. After a short period of activity. C. After a prolonged period of activity.

In the living serous gland,—*e. g.*, parotid,—during rest, the secretory cells lining the acini of the gland are seen to be filled with fine granules, which are often so abundant as to obscure the nucleus and enlarge the cells until the lumen of the acinus is almost obliterated. (See Fig. 11.) When the gland begins to secrete the saliva, the granules disappear from the outer boundary of the cells, which then become clear and distinct. At the end of the secretory activity the cells have been freed of granules and have become smaller and more distinct in outline. It would seem that the granular matter is formed in the cells during the period of rest and discharged into the ducts during the activity of the gland.

In the mucous glands—*e. g.*, submaxillary and sublingual—the changes that occur in the cells are somewhat different. (See Fig. 12.)

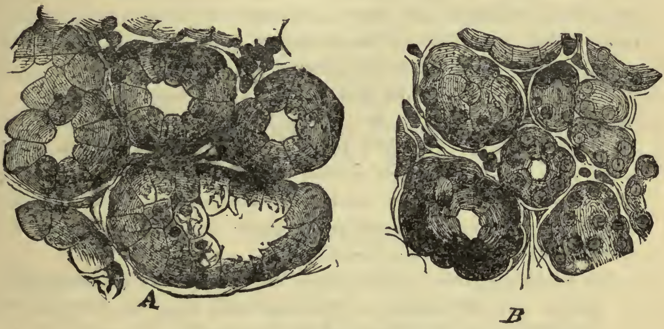


FIG. 12.—SECTION OF A MUCOUS GLAND.—(*Lavdowsky.*)
A. In a state of rest. B. After it has been for some time actively secreting.

During the intervals of digestion the cells lining the gland are large, clear, and highly refractive, and contain a large quantity of mucigin. After secretion has taken place the cells exhibit a marked change. The mucigin cells have disappeared, and in their place are cells which are small, dark, and composed of protoplasm. It would appear that the cells, during rest, elaborate the mucigin, which is discharged into the tubules during secretory activity, to become part of the secretion.

Saliva is an opalescent, slightly viscid, alkaline fluid, having a specific gravity of 1.005. Microscopic examination reveals the presence of salivary corpuscles and epithelial cells. Chemically it is composed of water, proteid matter, a ferment (*ptyalin*), and inorganic salts. The amount secreted in twenty-four hours is about 2½ lbs. Its function is twofold:

1. *Physical.*—Softens and moistens the food, agglutinates it, and facilitates swallowing.

2. *Chemic.*—Converts *starch* into *sugar.* This action is due to the presence of the organic ferment, ptyalin. Ptyalin is an amorphous nitrogenized substance, which can be precipitated from the saliva by calcium phosphate. Its power of converting starch into sugar is manifested most decidedly at the temperature of the living body and in a slightly alkaline medium. The conversion of starch into sugar takes place through several stages, the nature of which depends upon the structure of the starch granule. This consists of two portions, a stroma of cellulose and a contained material, *granulose,* which is the more abundant and important of the two. When subjected to the action of boiling water, the starch granule swells up and bursts, forming a viscid, opalescent mass of starch paste. If saliva be now added to this paste and kept at a temperature of 104° F. for a few minutes, the paste becomes clear and limpid. The first stage in the digestion is now complete, with the formation of soluble starch. If the action of saliva be continued, a number of substances intermediate between starch and sugar are formed, to which the name dextrin has been given. Among these may be mentioned:
   - (*a*) *Erythrodextrin,* which gives the reddish-brown color with iodin. As the digestion continues and sugar is formed, the erythrodextrin disappears, giving way to—
   - (*b*) *Achroödextrin,* which yields no coloration with iodin, but which may be precipitated by alcohol.

The sugar formed by the action of saliva is *maltose,* the formula for which is $C_{12}H_{22}O_{11}$. A small quantity of dextrose is also formed.

NERVE MECHANISM OF INSALIVATION.

Afferent Nerves.	*Efferent Nerves.*
1. Lingual branch of 5th pair.	1. Auriculotemporal branch of 5th pair, for parotid gland.
2. Glossopharyngeal.	2. Chorda tympani, for submaxillary and sublingual glands.

The centers regulating the secretion are located in the medulla oblongata. The nerve mechanism is excited to action by nerve impulses developed by the contact of the food with the terminal filaments of afferent nerves in the mucous membrane of the mouth. These nerve impulses are transmitted by afferent nerves to the medulla oblongata where they are transformed into motor impulses which are then transmitted through efferent nerves to the blood-vessels and epithelium of the glands.

Stimulation of the auriculotemporal branch increases the flow of saliva from the parotid gland; *division* arrests it.

Stimulation of the chorda tympani is followed by a dilatation of the blood-vessels of the submaxillary and sublingual glands, an increased flow of blood and an abundant discharge of a thin saliva; *division* of the nerve arrests the secretion.

Stimulation of the cervical sympathetic is followed by a contraction of the blood-vessels, a diminished flow of blood, and a diminution of the secretion, which now becomes thick and viscid; *division* of the sympathetic is not, however, followed by complete dilatation of the vessels. There is evidence of the existence of a local vasomotor mechanism, which is *inhibited* by the chorda tympani, and augmented by the sympathetic.

DEGLUTITION.

Deglutition is the act of transferring food from the mouth into the stomach, and may be divided into *three* stages:

1. The passage of the bolus from the mouth into the pharynx.
2. From the pharynx into the esophagus.
3. From the esophagus into the stomach.

In the *first stage,* which is entirely voluntary, the mouth is closed and respiration momentarily suspended; the tongue, placed against the roof of the mouth, arches upward and backward, and forces the bolus into the fauces.

In the *second stage,* which is entirely reflex, the palate is made tense and directed upward and backward by the levatores palati and tensores palati muscles; the bolus is grasped by the superior constrictor muscle of the pharynx and rapidly forced into the esophagus.

The food is prevented from entering the *posterior nares* by the uvula and the closure of the posterior half-arches (the palatopharyngeal muscles); from entering the *larynx* by its ascent under the base of the tongue and the action of the epiglottis.

In the *third stage* the longitudinal and circular muscle-fibers, contracting from above downward, *strip* the bolus into the stomach.

GASTRIC DIGESTION.

The Stomach.—Immediately beyond the termination of the esophagus the alimentary canal expands and forms a receptacle for the temporary retention of the food. To this dilatation the term stomach has been applied. This organ is somewhat pyriform in outline, and occupies the upper part of the abdominal cavity. It is about 13 inches long, 5 deep, and 3½ wide, and has a capacity of about five pints. It presents two orifices, the cardiac or esophageal, and the pyloric; two curvatures, the lesser and the greater.

The left or cardiac end of the stomach is enlarged, and forms the fundus; the right end is much narrower, and forms the pylorus. The stomach possesses three coats:

1. The serous, or reflection of the peritoneum.
2. The muscular, the fibers of which are arranged in a longitudinal, a circular, and an oblique direction. At the pyloric end the circular fibers increase in number and form a thick ring or band, which is known as the sphincter of the pylorus.
3. The mucous, which is somewhat larger than the muscular coat, and in consequence is thrown into folds or rugæ. The surface of the mucous coat is covered by tall, narrow, columnar epithelium.

Gastric Juice.—During the period of time the food remains in the stomach it is subjected to the disintegrating action of an acid fluid, the gastric juice. This fluid, secreted from glands in the mucous membrane, is thoroughly incorporated with the food in consequence of the contractions of the muscular coat. The food is gradually liquefied and reduced to a form which partly fits it for passage into the small intestine and for absorption into the blood. Gastric juice, when obtained in a pure state, is a clear, colorless fluid, decidedly acid in reaction, with a specific gravity of 1005. It is composed of the following ingredients:

COMPOSITION OF GASTRIC JUICE.

Water	994.404
Hydrochloric acid	0.200
Organic matter	3.195
Inorganic salts	2.201
	1000.000

The water forms by far the largest part of this fluid, and serves the purpose of holding the other ingredients in solution, and by its saturating power brings them into relation with the constituents of the food. Of the inorganic salts the sodium and potassium chlorids are the most abundant and important.

The *hydrochloric acid,* which exists in a free state, is present in variable amounts. In the foregoing table the number of parts a thousand is much smaller than is usually stated. According to most observers, hydrochloric acid is present to the extent of from 0.2 to 0.3 part a hundred. Though secreted as soon as the food enters the stomach, the acid can not be detected in the free state until after the lapse of from thirty to forty minutes. It acidulates the food and prevents fermentative changes.

The *pepsin,* which is present in gastric juice associated with the organic matter, is a hydrolytic ferment or enzyme. When freed from its associations and obtained in a pure state, pepsin presents the characteristics of a colloid body, and resembles in its reactions the albuminoids. It has the power, when brought into relation with acidulated proteids, of transforming them into new forms capable of absorption into the blood.

Rennin.—In addition to pepsin a second ferment exists in the gastric juice, to which the term *rennin* has been given. It possesses the power of coagulating the *caseinogen* of milk. It exists in the mucous membrane, from which it can be extracted by appropriate means. When rennin acts on caseinogen, the latter is split into insoluble *casein* and a soluble albumin. Calcium phosphate is essential to the action of this enzyme.

Gastric Glands.—Embedded within the mucous membrane are to be found enormous numbers of tubular glands, which though resembling one another in general form, differ in their histologic details in various portions of the stomach.

In the cardiac end or fundus the glands consist of several long tubules, opening into a short, common duct, which opens by a wide mouth on the surface of the mucous membrane. Each gland consists primarily of a basement membrane lined by epithelial cells. In the duct the epithelium is of the columnar variety, resembling that covering the surface of the mucous membrane. The secretory portion of the tubule is lined by a layer of short, polyhedral, granular, and nucleated cells, which, as they border the lumen of the tubule, and thus occupy the central portion of the gland, are termed *central* cells. At irregular intervals, between the central cells and the wall of the tubule, are found large, oval, reticulated cells, which, on account of their position, are termed *parietal* cells. (See Fig. 13.)

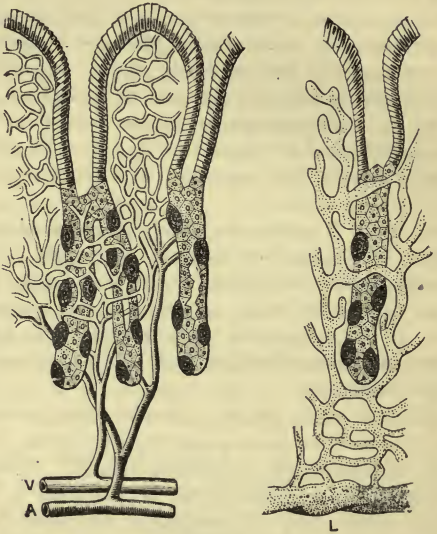


FIG. 13.

Diagram showing the relation of the ultimate twigs of the blood-vessels, V. and A, and of the absorbent radicles to the glands of the stomach and the different kinds of epithelium—viz., above cylindric cells; small, pale cells in the lumen, outside which are the dark ovoid cells.—(*Yeo's "Text-book of Physiology."*)

Each parietal cell is in relation with a system of fine canals, which open directly into the lumen of the gland. It is estimated that the fundus contains about five million glands. In the pyloric end of the stomach the glands are generally branched at their lower extremities, and the common duct is long and wide. The duct is lined by columnar epithelium, while the secreting part is lined by short, slightly columnar, granular cells. The parietal cells are entirely wanting. The epithelium covering the surface of the mucous membrane is tall, narrow and cylindric in shape, and consists of mucus-secreting goblet cells. The outer half of the cell contains a substance, mucinogen, which produces mucin. The gastric glands in both situations are surrounded by a fine connective tissue, which supports blood-vessels, nerves, and lymphatics.

Changes in the Cells During Secretion.—During the periods of rest and secretory activity the cells of the glands undergo changes in structure which are supposed to be connected with the production of the pepsin and hydrochloric acid. During rest, the protoplasm of the central cells becomes filled with granular matter; during the time of secretion this disappears, presumably passing into the lumen of the tubule, and as a result the protoplasm becomes clear and hyalin in appearance. The granular material is probably the mother substance, *pepsinogen,* which, inactive in itself, yields the active ferment, pepsin. The parietal cells during digestion increase in size, but do not become granular. It is at this period that they secrete the hydrochloric acid. After digestion they rapidly diminish in size and return to their former condition. The pyloric glands secrete pepsin only.

Mechanism of Secretion.—In the intervals of digestion, the mucous membrane of the stomach is covered with a layer of mucus. As soon as the food passes from the esophagus into the stomach, the blood-vessels dilate, the circulation becomes more active, and the membrane assumes a bright red appearance. Coincidentally, small drops of gastric juice begin to exude from the glands, which as they increase in number, run together and trickle down the sides of the stomach. This pouring out of fluid continues during the presence of food in the stomach.

The secretion of gastric juice is a reflex act, taking place through the central nervous system and called forth in response to the stimulus of food in the stomach. That the central nervous system also directly influences the production of the secretion is shown by the fact that emotion, such as fear or anger, will arrest or vitiate the normal secretion. The reflex nature of the process can be shown by experimentation upon the pneumogastric nerve. If during digestion, when the peristaltic movements are active and the gastric mucous membrane is flushed and covered with gastric juice, the pneumogastric nerves are divided on both sides, the mucous membrane becomes pale, the secretion is arrested, and the peristaltic movements become less marked. Stimulation of the peripheral end produces no constant effects; stimulation of the central end, however, is at once followed by dilatation of the vessels, flushing of the mucous membrane, and reëstablishment of the secretion. It is evident, therefore, that during digestion afferent impulses are passing up the pneumogastrics to the medulla; efferent impulses, in all probability, pass through the fibers of the sympathetic nervous system to the blood-vessels and glands concerned in the elaboration of the gastric juice. After all the nerve connections of the stomach are divided, the secretion of a small quantity of juice continues for several days. This has been attributed to the action of a local nervous mechanism and to the direct action of the food upon the protoplasm of the secreting cells.

Chemic Action of the Gastric Juice.—By the combined influence of the contraction of the muscular walls, the action of the gastric juice, and the temperature, the food is reduced to a semiliquid condition and acquires a distinct acid odor. This semifluid mass will vary in composition and appearance according to the nature of the food. To this matter the term *chyme* has been given.

Meat is rapidly disintegrated by the solution of its connective tissue. The fibers thus separated are readily broken up into particles by solution of the sarcolemma. Well-cooked meat is more easily digested, owing to the conversion of the connective tissue into gelátin.

Connective tissues in the raw or imperfectly gelatinized condition are very slowly dissolved. Cartilage, tendons, and even bones will in time be corroded and liquefied.

Vegetables are not easily digested unless thoroughly prepared by sufficient cooking. The nutritive principles are inclosed by cellulose walls, which are not affected by gastric juice. The influence of heat and moisture softens and ruptures the cellulose walls so as to permit the introduction of gastric juice and the solution of its nutritive principles.

The **principal action** of the gastric juice, however, is the transformation of the different proteid principles of the food into *peptones,* the intermediate stages of which are due to the influence of the acid and pepsin respectively. As soon as any one of the albumins is penetrated by the acid it is converted into *acid-albumin,* a fact which indicates that the first step in gastric digestion is the acidification of the proteids. This having been accomplished, the pepsin becomes operative and in a varying length of time transforms the acid-albumin into a new form of proteid termed *peptone*. In this transformation it is possible to isolate intermediate bodies by the addition of ammonium and magnesium sulphates, to which the term *albumoses* or *proteoses* has been given. Because of the order in which they are obtained they have been divided into primary and secondary. The primary proteoses are in turn separated into proto- and hetero-albumose; the secondary proteoses are termed deutero-albumose. This supposed change is represented by the following scheme:

$$\begin{array}{c} \text{Albumin.} \\ | \\ \text{Acid-albumin.} \\ | \\ \begin{array}{c} \text{Albumoses} \\ \text{or} \\ \text{Proteoses.} \end{array} \left\{ \begin{array}{l} \text{Primary} \\ \text{(proto and hetero).} \\ \text{Secondary} \\ \text{(deutero).} \end{array} \right. \\ | \\ \text{Peptone.} \end{array}$$

Peptones.—Peptones are the final products of the digestion of proteid bodies, and differ from the bodies from which they are derived in the following particulars:

1. They are *diffusible,—i. e.,* capable of passing readily through animal membranes,—a condition essential for their absorption.
2. They are *soluble* in water and in saline solution.
3. They are *non-coagulable* by heat and nitric or acetic acids. They can be readily precipitated, however, by tannic acid, by bile acids, and by mercuric chlorid.
4. They are *absorbable* and *assimilable,* soon becoming transformed into serum-albumin.

The **duration** of gastric digestion will depend largely upon the quantity and quality of the food. The digestion of the average meal occupies from three to five hours.

Movements of the Stomach.—During the period of gastric digestion the walls of the stomach become the seat of a series of movements, somewhat peristaltic in character, which serve not only to incorporate the gastric juice with the food, but also serve to eject the liquefied portions of the food into the intestine.

After the entrance of the food both the cardiac and pyloric orifices are closed by the contraction of their sphincters. Within five minutes (in the cat) annular constrictions begin in the pyloric region which move peristaltically towards the pylorus. As digestion proceeds these constrictions or contractions become more frequent and more vigorous. The result is a trituration and liquefaction of the food. So soon as it is liquefied the pylorus relaxes and permits of its discharge into the intestine. The pylorus then closes and further preparation of food goes on. From time to time the pylorus relaxes to permit the discharge of prepared and liquefied food until digestion is completed. In the cardiac region there is an absence of peristalsis though the muscle wall is in a state of active tone. The fundus acts as a reservoir for food and delivers its contents to the pyloric region as rapidly as it is ready to receive them.

TABLE SHOWING DIGESTIBILITY OF VARIOUS ARTICLES OF FOOD.

	Hours.	*Minutes.*
Eggs, whipped	1	20
" soft-boiled	3	—
" hard-boiled	3	30
Oysters, raw	2	55
" stewed	3	30
Lamb, broiled	2	30
Veal, "	4	—
Pork, roasted	5	15
Beefsteak, broiled	3	—
Turkey, roasted	2	25
Chicken, boiled	4	—
" fricasseed	2	45
Duck, roasted	4	—
Soup, barley, boiled	1	30
" bean, "	3	—
" chicken, "	3	—
" mutton, "	3	30
Liver, beef, broiled	2	—
Sausage "	3	20
Green corn, boiled	3	45
Beans, "	2	30
Potatoes, roasted	2	30
" boiled	3	30
Cabbage, "	4	30
Turnips, "	3	30
Beets, "	3	45
Parsnips, "	2	30

INTESTINAL DIGESTION.

The process of digestion as it takes place in the small intestine is exceedingly important and complex, and is brought about by the action of the pancreatic juice, the bile, and the intestinal juice.

The contents of the stomach at the close of gastric digestion consist of water, inorganic salts, peptones, undigested albumins and starches, maltose, cane-sugar, liquefied fats, cellulose, and the indigestible portions of meats, cereals, fruits, etc. This so-called chyme is quite acid in reaction, and upon its passage through the now open pylorus into the intestine it excites a reflex stimulation and secretion of the intestinal fluids, which are decidedly alkaline in reaction, and which have a neutralizing action on the chyme. As soon as the latter becomes alkaline and gastric digestion is arrested, the various phases ot intestinal digestion begin which eventuate in the transformation of all the remaining undigested nutritive materials into absorbable and assimilable compounds.

The **small intestine** is about 22 feet in length and about 1½ inches in diameter. Like the stomach, it possesses three coats, as follows:

1. The *serous,* or peritoneal.
2. The *muscular,* the fibers of which are arranged for the most part circularly. Some of the fibers are so arranged as to form longitudinal bands.
3. The *mucous,* which presents a series of transverse folds, known as the *valvulæ conniventes.*

Intestinal Glands.—In that portion of the small intestine known as the duodenum are to be found a number of small, branched, tubular glands (Brunner's), the acini of which are lined by short, cylindric cells, similar to those lining the pyloric glands. From the duodenum to the termination of the intestine the mucous membrane contains an enormous number of tubular glands (Lieberkühn's), formed by an inversion of the basement membrane and lined by epithelial cells. The common secretion of these intestinal glands forms the intestinal juice. This is a thin, opalescent, slightly yellowish fluid, alkaline in reaction, and contains water, salts and proteid matter.

The *function* of the intestinal juice is but incompletely known. It appears to have the power of converting starch into dextrose; It is doubtful whether it is capable of digesting either albumins or fats. Its most distinctive action is the inversion of cane-sugar, maltose, and lactose into dextrose, thus preparing them for absorption. This change is dependent on the presence of a ferment body known as *invertin.*

The **pancreatic juice** is secreted by the pancreas, a flattened gland, about six inches long, running transversely across the posterior wall of the abdomen behind the stomach; its duct opens into the duodenum.

The pancreas is similar in structure to the salivary glands, and consists of a system of ducts terminating in acini. The acini are tubular or flask-shaped, and consist of a basement membrane lined by a layer of cylindric, conic cells, which encroach upon the lumen of the acini. The cells exhibit a difference in their structure (Fig. 14), and may be said to consist of two zones—viz., an *outer parietal zone,* which is transparent and apparently homogeneous, staining rapidly with carmin; an *inner zone,* which borders the lumen, and is distinctly granular and stains but slightly with carmin. These cells undergo changes similar to those exhibited by the cells of the salivary glands during and after active secretion. As soon as the secretory activity of the pancreas is established, the granules disappear, and the inner granular layer becomes reduced to a very narrow border,

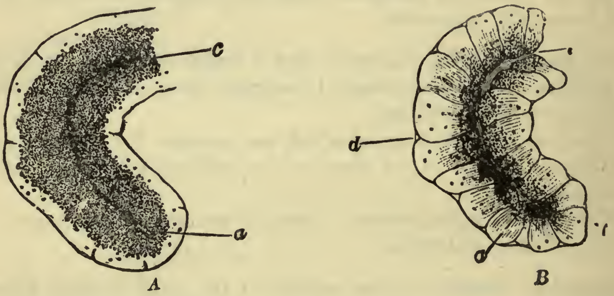


FIG. 14.—ONE SACCULE OF THE PANCREAS OF THE RABBIT IN DIFFERENT STATES OF ACTIVITY.—(*Yeo's "Text-book of Physiology," after Kühne and Lea.*)

A. After a period of rest, in which case the outlines of the cells are indistinct and the inner zone—*i. e.,* the part of the cells (*a*) next the lumen (*c*)—is broad and filled with fine granules. *B.* After the gland has poured out its secretion, when the cell outlined (*d*) are clearer, the granular zone (*a*) is smaller, and the clear outer zone is wider.

while the outer zone increases in size and occupies nearly the entire cell. During the intervals of secretion, however, the granular layer reappears and increases in size until the outer zone is reduced to a minimum. It would seem that the granular matter is formed by the nutritive processes occurring in the gland during rest, and is discharged during secretory activity into the ducts, and takes part in the formation of the pancreatic secretion.

The pancreatic juice is transparent, colorless, strongly alkaline, and viscid, and has a specific gravity of 1040. It is one of the most important of the digestive fluids, as it exerts a transforming influence upon all classes of alimentary principles, and has been shown to contain at least three distinct ferments. It has the following composition:

COMPOSITION OF PANCREATIC JUICE.

Water	900.76
Albuminoid substances	90.44
Inorganic salts	8.80
	1,000.00

The pancreatic juice is characterized by its action:

1. Upon *starch*. When starch is subjected to the action of the juice, it is at once transformed into maltose; the change takes place more rapidly than when saliva is added. This action is caused by the presence of a special ferment, *amylopsin*.
2. Upon *albumin*. The proteid bodies which escape digestion in the stomach are converted into peptones by the action of the alkali and ferment. The first effect of the alkali is to change the proteid into an *alkali-albumin*, a fact which indicates that in the digestion of albumin by pancreatic juice, the first stage is alkalinization. This having been accomplished, the ferment *trypsin* transforms the alkali-albumin into peptone. For the same reasons it is believed that here also these bodies are preceded in their development by albumoses, of which there are probably two forms. Long-continued action of the pancreatic juice, as previously stated, decomposes the peptone into leucin, tyrosin, etc.
3. Upon *fats*. The most striking action of the pancreatic juice is the *emulsification* of the fats or their subdivision into minute particles of microscopic size. This change takes place rapidly, and depends upon the alkalinity of the fluid and the quantity of albumin present,

combined with the intestinal movements. The *neutral fats* are also decomposed into their corresponding *fatty acids* and *glycerin;* The acids thus set free unite with the alkaline bases present in the intestine and form soaps. This decomposition of the neutral fats is caused by the ferment, *steapsin.*

The **bile** has an important function in the elaboration of the food and in its preparation for absorption. It is a golden-brown, viscid fluid, having a neutral or alkaline reaction and a specific gravity of 1020.

COMPOSITION OF BILE.

Water	859.2
Sodium glycocholate Sodium taurocholate	91.4
Fat	9.2
Cholesterin	2.6
Mucus and coloring-matter	29.8
Salts	7.8
	1,000.0

The *biliary salts,* sodium glycocholate and taurocholate, are characteristic ingredients, and by the process of secretion are formed in the liver from materials furnished by the blood. It is probable that they are derived from the nitrogenized compounds, though the stages in the process are unknown. They are reabsorbed from the small intestine to play some ulterior part in nutrition.

Cholesterin is a product of waste taken up by the blood from the nerve tissues and excreted by the liver. It crystallizes in the form of rhombic plates which are quite transparent. When retained within the blood, it gives rise to the condition of *cholesteremia,* attended with severe nervous symptoms. It is given off in the feces under the form of stercorin.

The *coloring-matters* which give the tints to the bile are *biliverdin* and *bilirubin,* and are probably derived from the coloring-matter of the blood. Their presence in any fluid can be recognized by adding to it nitric acid containing nitrous acid, when a play of colors is observed, beginning with green, blue, violet, red and yellow.

The **bile** is both a secretion and an excretion; it is constantly being formed and discharged by the hepatic ducts into the gall-bladder, in which it is stored up during the intervals of digestion. As soon as food enters the intestines it is poured out abundantly by the contraction of the walls of the gall-bladder.

The *amount* secreted in twenty-four hours is about 2½ pounds.

Functions of the Bile:

1. It assists in the *emulsification* of the fats and promotes their absorption.
2. It tends to prevent putrefactive changes in the food.
3. It stimulates the secretion of the intestinal glands, and excites the normal peristaltic movement of the bowels.

The digested food, the *chyme,* is a grayish, pultaceous mass, but as it passes through the intestines it becomes yellow from admixture with the bile. It is propelled onward by vermicular motion—by the contraction of the circular and longitudinal muscle-fibers.

During the passage of the digesting food through the intestinal canal the nutritive products—the peptones, the dextrose and levulose, the fatty emulsions, the fatty acids and their soaps—are absorbed into the blood, while the undigested residue is carried onward by the peristaltic movements through the ileo-cecal valve into the large intestine.

Intestinal Fermentation.—Owing to the favorable conditions for fermentative and putrefactive processes—*e. g.,* heat, moisture, oxygen, microörganisms—the food, when consumed in excessive quantity or when acted upon by defective secretions, undergoes a series of decomposition changes which are attended by the production of gases and various chemic compounds. Grape-sugar and maltose are partially split into lactic acid, this into butyric acid, carbon dioxid, and hydrogen. Fats are reduced to glycerol and fatty acids; the glycerol, according to the organisms present, yields succinic and other fatty acids, carbon dioxid, and hydrogen.

The proteids, under the prolonged action of the pancreatic juice, are decomposed, and yield leucin and tyrosin; the former is split into valerianic acid, ammonia, and carbon dioxid; the latter is split into indol, which is the antecedent of indican in the urine. Skatol is another proteid derivative constantly present in the fecal substance.

Intestinal Movements.—During intestinal digestion the walls of the intestine exhibit two kinds of movement, viz., a rhythmic segmentation and a peristalsis. By the former the food is divided into segments and by the latter, it is carried down the intestine. Shortly after the entrance of the food into the intestine, segmentation begins by a contraction of bands of circular muscle fibers. So soon as a mass of food is divided into segments each segment is in turn again divided by similar contractions. The lower half of each segment then unites with the upper half of the segment below to commingle with it and to expose new surfaces of the food mass to contact with the intestinal juices and to the mucous membrane. A continual repetition of this process results in a thorough mixing of the food with the digestive juices. Subsequent peristaltic waves slowly carry the food down the intestine.

The **large intestine** extends from the ileo-cecal valve to the anus, and is about five feet in length. Like the stomach it consists of three coats: the serous, the muscular, and mucous. The mucous membrane contains a number of mucous glands, the secretion from which lubricates the surface of the canal. The ascending portion of the large intestine possesses the power of absorption, and hence its contents become less liquid and more consistent. As the residue passes toward the sigmoid flexure it acquires the characteristics of fecal matter. This residue consists of the undigested portions of the food, decomposition products, mucus, and inorganic salts.

Defecation is the voluntary act of extruding the feces from the rectum, and is accomplished by a relaxation of the sphincter ani muscle and by the contraction of the muscular walls of the rectum, aided by the contraction of the abdominal muscles.

ABSORPTION.

The term absorption is applied to the passage or transference of material into the blood from the tissues, from the serous cavities, and from the mucous surfaces of the body. The most important of these surfaces, especially in its relation to the formation of blood, is the mucous surface of the alimentary canal; for it is from this organ that new materials are derived which maintain the quality and quantity of the blood. The absorption of materials from the interstices of the tissues is to be regarded rather as a return to the blood of liquid nutritive material which has escaped from the blood-vessels for nutritive purposes, and which, if not returned, would lead to an accumulation of such fluid and the development of dropsical conditions.

The anatomic mechanisms involved in the absorptive processes are, primarily, the *lymph-spaces,* the *lymph-capillaries,* and the *blood-capillaries;* secondarily, the *lymphatic vessels* and *larger blood-vessels.*

Lymph-spaces, Lymph-capillaries, Blood-capillaries.—Everywhere throughout the body, in the intervals between connective-tissue bundles and in the interstices of the several structures of which an organ is composed, are found spaces of irregular shape and size, determined largely by the nature of the organ in which they are found, which have been termed *lymph-spaces* or *lacunæ,* from the fact that during the living condition they are continually receiving the lymph which has escaped from the blood-vessels throughout the body. In addition to the connective-tissue lymph-spaces, various observers have described special lymph-spaces in the testicle, kidney, liver, thymus gland, and spleen; in all secreting glands between the basement membrane and blood-vessels; around blood-vessels (perivascular spaces), and around nerves. The *serous cavities* of the body—peritoneal, pleural, pericardial, etc.—may also be regarded as lymph-spaces, which are in direct communication by open mouths or *stomata* with the lymph capillaries. This method of communication is not only true of serous membranes, but to some extent also of mucous membranes. The cylindric sheaths and endothelial cells surrounding the brain, spinal cord, and nerves can also be looked upon as lymph-spaces in connection with lymph-capillaries.

The *lymph-capillaries,* in which the lymph-vessels proper take their origin, are arranged in the form of plexuses of quite irregular shape. In most situations they are intimately interwoven with the blood-vessels, from which, however, they can be readily distinguished by their larger caliber and irregular expansions. The wall of the lymph-capillary is formed by a single layer of epithelioid cells, with sinuous outlines, and which accurately dovetail with one another. In no instance are valves found. In the villus of the small intestine the beginning of the lymphatic is to be regarded as a lymph-capillary, generally club-shaped, which at the base of the villus enters a true lymphatic; at this point a valve is situated, which prevents regurgitation. The lymph capillaries anastomose freely with one another, and communicate on the one hand with the lymph-spaces, and on the other with the lymphatic vessels proper.

As the shape, size, etc., of both lymph-spaces and capillaries are determined largely by the nature of the tissues in which they are contained, it is not always possible to separate the one from the other. Their function, however, may be regarded as similar—viz., the collection of the lymph which has escaped from the blood-vessels, and its transmission onward into the regular lymphatic vessels.

The *blood-capillaries* not only permit the escape of the liquid nutritive portions of the blood through their delicate walls, but are also engaged in the reabsorption of this transudate, as well as in the absorption of new materials from the alimentary canal. The extensive capillary network which is formed by the ultimate subdivision of the arterioles in the submucous tissue and villi of the small intestine forms an anatomic arrangement well adapted for absorption. It is now well known that in the absorption of the products of digestion the blood-capillaries are more active than the lymph-capillaries.

Lymph-Vessels.—These constitute a system of minute, delicate transparent vessels, found in nearly all the organs and tissues of the the body. Having their origin at the periphery in the lymph-capillaries and spaces, they rapidly converge toward the trunk of the body and empty into the thoracic duct. In their course they pass through numerous small ovoid bodies, the lymphatic glands.

The lymph-vessels of the small intestines—*the lacteals*—arise within the villous processes which project from the inner surface of the intestine throughout its entire extent. The wall of the villus is formed by an elevation of the basement membrane, and is covered by a layer of columnar epithelial cells. The basis of the villus consists of adenoid tissue, a fine plexus of blood-vessels, unstriped muscle-fibers, and the lacteal vessel. The adenoid tissue consists of a number of intercommunicating spaces, containing leukocytes. The lacteal vessel possesses a thin but distinct wall composed of endothelial plates, with here and there openings which bring the interior of the villus into communication with the spaces of the adenoid tissue.

The *structure* of the larger vessels resembles that of the veins, consisting of three coats:

1. *External,* composed of fibrous tissue and muscle fibers, arranged longitudinally.
2. *Middle,* consisting of white fibers and yellow elastic tissue, non-striated muscle-fibers, arranged transversely.

3. *Internal,* composed of an elastic membrane, lined by endothelial cells.

Throughout their course are found numerous *semilunar valves,* opening toward the larger vessels, formed by a folding of the inner coat and strengthened by connective tissue.

Lymph Glands.—The lymph glands consist of an external capsule composed of fibrous tissue which contains non-striped muscle-fibers; from its inner surface septa of fibrous tissue pass inward and subdivide the gland-substance into a series of compartments, which communicate with one another. The blood-vessels which penetrate the gland are surrounded by fine threads, forming a follicular arrangement, the meshes of which contain numerous lymph-corpuscles. Between the follicular threads and the wall of the gland lies a lymph-channel traversed by a reticulum of adenoid tissue. The lymph-vessels, after penetrating this capsule, pour their lymph into this channel, through which it passes; it is then collected by the efferent vessels and transmitted onward. The lymph-corpuscles which are washed out of the gland into the lymph-stream are formed, most probably, by division of preëxisting cells.

The **thoracic duct** is the general trunk of the lymphatic system; into it the vessels of the lower extremities, of the abdominal organs, of the left side of the head, and of the left arm empty their contents. It is about twenty inches in length, arises in the abdomen, opposite the third lumbar vertebra, by a dilatation (the *receptaculum chyli*), ascends along the vertebral column to the seventh cervical vertebra, and terminates in the venous system at the junction of the internal jugular and subclavian veins on the left side. The lymphatics of the right side of the head, of the right arm, and of the right side of the thorax terminate in the *right thoracic duct,* about one inch in length, which joins the venous system at the junction of the internal jugular and subclavian on the right side.

The general arrangement of the lymph vessels is shown in figure 15.

The **blood-vessels** which are concerned in the conduction of fresh nutritive material from the alimentary canal have their origin in the elaborate capillary network in the mucous membrane. The small veins which emerge from the network gradually unite, forming larger and larger trunks, which are known as the gastric, superior, and inferior mesenteric veins. These finally unite to form the portal vein, a short trunk about three inches in length. The portal vein

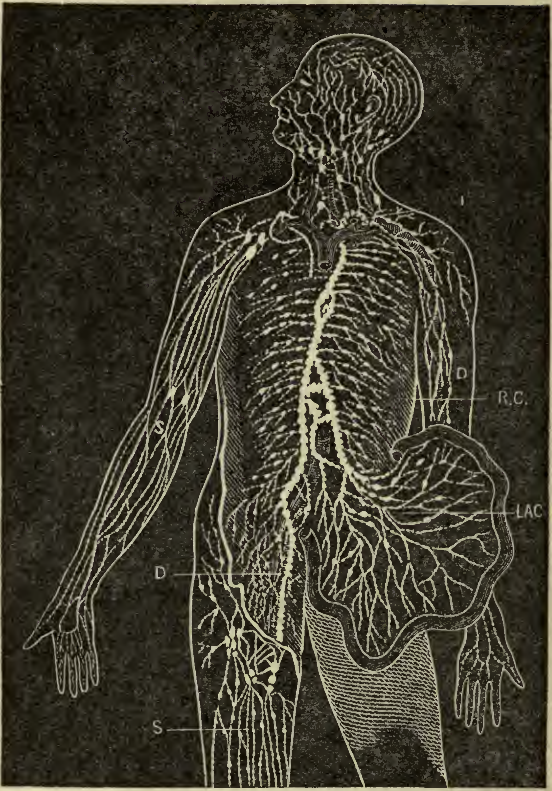


FIG. 15.—DIAGRAM SHOWING THE COURSE OF THE MAIN TRUNKS OF THE ABSORBENT SYSTEM.—(*Yeo's "Text-book of Physiology."*)

The lymphatics of lower extremities (D) meet the lacteals of intestines (LAC) at the receptaculum chyli (RC), where the thoracic duct begins. The superficial vessels are shown in the diagram on the right arm and leg (S), and the deeper ones on the arm to the left (D). The glands are here and there shown in groups. The small right duct opens into the veins on the right side. The thoracic duct opens into the union of the great veins of the left side of the neck (T).

enters the liver at the transverse fissure, after which it forms a fine capillary plexus ramifying throughout the substance of the liver; from this plexus the hepatic veins take their origin, and finally empty the blood into the vena cava inferior. (See Fig. 16.)

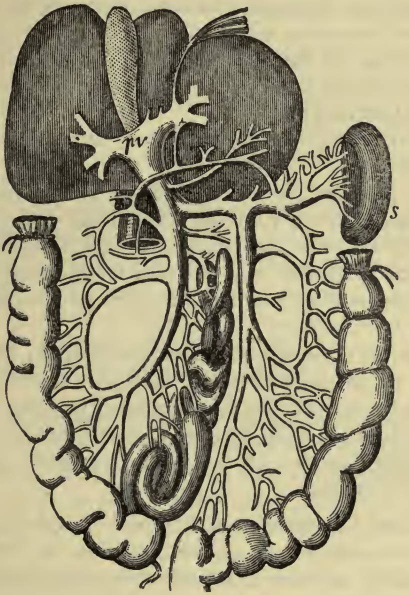


FIG. 16.

Diagram of the portal vein (*pv*) arising in the alimentary tract and spleen (*s*), and carrying the blood from these organs to the liver.—(*Yeo's "Text-book of Physiology."*)

Absorption of Food.—Physiological experiments have demonstrated that the agents concerned in the absorption of new materials from the alimentary canal are:

1. The *blood-vessels* of the entire canal, but more particularly those uniting to form the portal vein.
2. The *lymph vessels* coming from the small intestine, which converge to empty into the thoracic duct.

As a result of the action of the digestive fluids upon the different classes of food principles—albumins, sugars, starches, and fats—there are formed *peptones, glucose,* and *fatty emulsion,* which differ from the former in being highly diffusible—a condition essential to their absorption. In order that these substances may get into the blood, they must pass through the layer of cylindric epithelial cells and the underlying basement membrane, and into the lymph-spaces of the villi and submucous tissue. The mechanism by which the cells effect this passage of the food is but imperfectly understood. Osmosis and filtration are conditions, however, made use of by the cells in the absorptive process.

The *products of digestion* find their way into the general circulation by two routes:

1. The *water, peptones, glucose,* and *soluble salts,* after passing into the lymph-spaces of the villi, pass through the wall of the capillary blood-vessel; entering the blood, they are carried to the liver by the vessels uniting to form the portal vein; emerging from the liver, they are emptied into the inferior vena cava by the hepatic vein.
2. The *emulsified fat* enters the lymph-capillary in the interior of the villus; by the contraction of the layer of muscle-fibers surrounding it its contents are forced onward into the lymph-vessels or *lacteals,* thence into the thoracic duct, and finally into the blood stream at the junction of the internal jugular and subclavian veins on the left side.

Properties and Composition of Lymph.—Lymph, as found in the lymph-vessels of animals, is a clear, colorless, or opalescent fluid, having an alkaline reaction, a saline taste, and a specific gravity of about 1040. It holds in suspension a number of corpuscles resembling in their general appearance the white corpuscles of the blood. Their number has been estimated at 8,200 per cubic millimeter,

COMPOSITION OF LYMPH.

Water	95.536
Proteids (serum-albumin, fibrin-globulin)	1.320
Extractives (urea, sugar, cholesterin)	1.559
Fatty matters	a trace
Salts	0.585
	100.000

though the number varies in different portions of the lymphatic system. As the lymph flows through the lymphatic gland it receives a large addition of corpuscles. Lymph-corpuscles are granular in structure, and measure $\frac{1}{2500}$ of an inch in diameter. When withdrawn from the vessels, lymph undergoes a spontaneous coagulation similar to that of blood, after which it separates in serum and clot.

Origin and Functions of Lymph.—Though the blood is the common reservoir of all nutritive materials, they are not available for nutritive purposes as long as they are confined within the blood-vessels. But owing to the character of the wall of the capillary blood-vessel, some of the constituents of the blood-plasma pass through it and are received by the tissue-spaces in which they come into contact with the tissue-cells. To the sum total of these materials the term lymph is given. Its function becomes apparent from its origin and composition, its situation and relation to the tissues. It is to furnish the tissue-cells with those nutritive materials which are necessary for their growth, repair and functional activity. It also receives all waste products that arise from their activity prior to their removal by the blood- and lymph-vessels.

Absorption of Lymph.—From the fact that lymph is being discharged more or less continuously from the thoracic duct, it is evident that lymph is being absorbed from the intercellular spaces; from which it may be inferred that more lymph is passing from the blood into the tissue-spaces than is necessary for the immediate needs of the tissues. To prevent an accumulation and an interference through pressure with the activities of the tissues, the excess is absorbed by the lymph-vessels and returned to the blood stream by way of the thoracic duct. It is likely that some of the constituents are absorbed by the blood-vessels.

Chyle.—Chyle is the fluid found in the lymph vessels, coming from the small intestine after the digestion of a meal containing fat. In the intervals of digestion the fluid of these lymphatics is identical in all respects with the lymph found in all other regions of the body. As soon as the emulsified fat passes into the lymph vessels and mingles with the lymph it becomes milky white in color, and the vessels which previously were invisible become visible, and resemble white threads running between the layers of the mesentery. Chyle has a composition similar to that of lymph, but it contains, in addition, numerous fatty granules, each surrounded by an albuminous envelope. When examined microscopically, the chyle presents a fine molecular basis, made up of the finely divided granules of fat.

COMPOSITION OF CHYLE.

Water	902.37
Albumin	35.16
Fibrinogen	3.70
Extractives	15.65
Fatty matters	36.01
Salts	7.11
	1,000.00

Forces Aiding the Movement of Lymph and Chyle.—The lymph and chyle are continually moving in a progressive manner from the periphery or beginning of the lymphatic system to the final termination of the thoracic duct. The force which primarily determines the movement of the lymph has its origin in the beginnings of the lymph-vessels, and depends upon the difference in pressure here and the pressure in the thoracic duct. The greater the quantity of fluid poured into the lymph-spaces, the greater will be the pressure and, consequently, the movement. The first movement of chyle is the result of a contraction of the muscle-fibers within the walls of the villus. At the time of contraction the lymph capillary is compressed and shortened, and its contents are forced onward into the true lymphatic. When the muscle-fibers relax, regurgitation is prevented by the closure of the valve in the lymphatic at the base of the villus.

As the walls of the lymph vessels contain muscle-fibers, when they become distended these fibers contract and assist materially in the onward movement of the fluid.

The contraction of the general muscular masses in all parts of the body, by exerting an intermittent pressure upon the lymphatics, also hastens the current onward; regurgitation is prevented by the closure of valves which everywhere line the interior of the vessels.

The respiratory movements aid the general flow of both lymph and chyle from the thoracic duct into the venous blood. During the time of an inspiratory movement the pressure within the thorax, but outside the lungs, undergoes a diminution in proportion to the extent of the movement; as a result, the fluid in the thoracic duct outside of the thorax, being under a higher pressure, flows more rapidly into the venous system. At the time of an expiration, the pressure rises and the flow is temporarily impeded, only to begin again at the next inspiration.

BLOOD.

The **blood** is a nutritive fluid containing all the elements necessary for the repair of the tissues; it also contains principles of waste absorbed from the tissues, which are conveyed to the various excretory organs and by them eliminated from the body.

The *total amount* of blood in the body is estimated to be about one thirteenth of the body-weight; from ten to twelve pounds in an individual of average physical development. The quantity varies during the twenty-four hours, the *maximum* being reached in the afternoon, the *minimum* in the early morning hours.

Blood is an opaque, red fluid, having an alkaline reaction, a saline taste, and a specific gravity of 1055.

The *opacity* is due to the refraction of the rays of light by the elements of which the blood is composed. The *color* varies in hue, from a bright scarlet in the arteries to a deep purple in the veins, due to the presence of a coloring-matter—*hemoglobin*—in different degrees of oxidation.

The *alkalinity* is constant, and depends upon the presence of the alkaline sodium phosphate, Na_2HPO_4.

The *saline taste* is due to the amount of sodium chlorid present.

The *specific gravity*, within the limits of health, ranges from 1045 to 1075.

The *odor* of the blood is characteristic, and varies with the animal from which it is drawn; it is due to the presence of caproic acid.

The *temperature* of the blood ranges from 98° F. at the surface to 107° F. in the hepatic vein; it loses heat by radiation and evaporation as it approaches the extremities and as it passes through the lungs.

Blood Consists of Two Portions:

1. The *liquor sanguinis* or *plasma*, a transparent, colorless fluid, in which are floating—

the joints where the movement takes place, and when the muscles are considered as sources of power for imparting movement to the levers, with the object of overcoming resistance or raising weights.

In mechanics, levers of three kinds or orders are recognized, according to the relative position of the *fulcrum* or axis of motion, the applied power, and the weight to be moved. (See Fig. 5.)

2. *Red and white corpuscles,* these constituting by weight less than one half (40 per cent.) of the entire amount of blood.

COMPOSITION OF PLASMA.

	Dalton.
Water	902.00
Albumin	53.00
Paraglobulin	22.00
Fibrinogen	3.00
Fatty matters	2.50
Crystallizable nitrogenous matters	4.00
Other organic matter	5.00
Mineral salts	8.50
	1,000.00

Water acts as a solvent for the inorganic matters and holds in suspension the corpuscular elements.

Albumin is the nutritive principle of the blood; it is absorbed by the tissues to repair their waste and is transformed into the organic basis characteristic of each structure.

Paraglobulin or *fibrinoplastin* is a soft, amorphous substance precipitated by sodium chlorid in excess, or by passing a stream of carbonic acid through dilute serum.

Fibrinogen also can be obtained by *strongly diluting* the serum and passing carbonic acid through it for a long time, when it is precipitated as a viscous deposit.

Fatty matter exists in the blood to the extent of about 0.25 per cent. Just after a meal rich in fat, this amount may be considerably increased. Within a few hours it disappears, though its ultimate fate is unknown.

Sugar is represented by dextrose. The amount present varies from 0.1 to 0.3 per cent. It is derived directly from the glycogen of the liver. Should the normal percentage be increased, the sugar is eliminated by the kidneys.

The *inorganic constituents* are chiefly sodium and potassium chlorids, sulphates and phosphates together with calcium and magnesium phosphates. The sodium chlorid is the most abundant, amounting to about 5.5 parts per thousand. The alkaline salts impart the alkaline reaction and promote the absorption from the tissues of the carbon dioxid.

Excrementitious matters are represented by carbonic acid, urea, creatin, creatinin, urates, oxalates, etc.; they are absorbed from the tissues by the blood and conveyed to the excretory organs, lungs, kidneys, etc.

Gases.—Oxygen, nitrogen, and carbonic acid exist in varying proportions.

BLOOD-CORPUSCLES.

The corpuscular elements of the blood occur under two distinct forms, which, from their color, are known as the *red* and *white* corpuscles.

The *red corpuscles* as they float in a thin layer of the liquor sanguinis are of a pale straw-color; it is only when aggregated in masses that they assume the bright red color. In form they are circular and biconcave; they have an average diameter of $\frac{1}{3200}$ of an inch.

In mammals, birds, reptiles, amphibia, and fish the corpuscles vary in size and number, gradually becoming larger and less numerous as the scale of animal life is descended, *e. g.*:

TABLE SHOWING COMPARATIVE DIAMETER OF RED CORPUSCLES.

Mammals.		*Birds.*		*Reptiles.*		*Amphibia.*		*Fish*	
Man,	$\frac{1}{3200}$	Eagle,	$\frac{1}{1812}$	Turtle,	$\frac{1}{1231}$	Frog,	$\frac{1}{1108}$	Perch,	$\frac{1}{2099}$
Chimpanzee,	$\frac{1}{3412}$	Owl,	$\frac{1}{1763}$	Tortoise,	$\frac{1}{1252}$	Toad,	$\frac{1}{1043}$	Carp,	$\frac{1}{2141}$
Orang,	$\frac{1}{3383}$	Sparrow,	$\frac{1}{2140}$	Lizard,	$\frac{1}{1555}$	Proteus,	$\frac{1}{400}$	Pike,	$\frac{1}{2000}$
Dog,	$\frac{1}{3542}$	Swallow,	$\frac{1}{2133}$	Viper,	$\frac{1}{1274}$	Siren,	$\frac{1}{420}$	Eel,	$\frac{1}{1745}$
Cat,	$\frac{1}{4404}$	Pigeon,	$\frac{1}{1973}$			Amphiuma,	$\frac{1}{363}$		
Hog,	$\frac{1}{4230}$	Turkey,	$\frac{1}{2045}$						
Horse,	$\frac{1}{4600}$	Goose,	$\frac{1}{1866}$						
Ox,	$\frac{1}{4267}$	Swan,	$\frac{1}{1806}$						

In man and the mammals the red corpuscles present neither a nucleus nor a cell wall, and are universally of a small size. They can be readily distinguished from the corpuscles of birds, reptiles, and fish, in which animals they are larger, oval in shape, and possess a well-defined nucleus.

The red corpuscles are exceedingly numerous, amounting to about 5,000,000 in a cubic millimeter of blood. In structure they consist of a firm, elastic, colorless framework,—the *stroma,*—in the meshes of which is entangled the coloring-matter— the *hemoglobin.*

CHEMIC COMPOSITION OF RED CORPUSCLES.

Water	688.00
Globulin	282.22
Hemoglobin	16.75
Fatty matter	2.31
Extractives	2.60
Mineral salts	8.12
	1,000.00

Hemoglobin, the coloring-matter of the corpuscles, is an albuminous compound, composed of C, O, H, N, S, and iron. It may exist in either an amorphous or a crystalline form. When deprived of all its oxygen, except the quantity entering into its intimate composition, the hemoglobin becomes purplish in color, and is known as *reduced hemoglobin.* When exposed to the action of oxygen, it again absorbs a definite amount and becomes scarlet in color, and is known as *oxyhemoglobin.* The amount of oxygen absorbed is 1.76 c.c. ($\frac{7}{10}$ of a cubic inch) for 1 mg. ($\frac{1}{64}$ of a grain) of hemoglobin.

It is this substance which gives the color to the venous and arterial blood. As the venous blood passes through the capillaries of the lungs the *reduced hemoglobin* absorbs the oxygen from the pulmonary air and becomes *oxyhemoglobin,* scarlet in color; the blood becomes arterial. When the arterial blood passes into the systemic capillaries, the oxygen is absorbed by the tissues; the hemoglobin becomes reduced, purple in color, and the blood becomes venous. A dilute solution of oxyhemoglobin gives two absorption bands between the lines D and E of the solar spectrum. Reduced hemoglobin gives but one absorption band, occupying the space existing between the two bands of the oxyhemoglobin spectrum.

The *function* of the red corpuscle is, therefore, to absorb oxygen and carry it to the tissues; the smaller the corpuscles and the greater the number, the greater is the quantity of oxygen absorbed, and, consequently, all the vital functions of the body become more active.

The *white corpuscles* are far less numerous than the red, the proportion being, on an average, about 1 white to from 350 to 400 red; they are globular in shape, and are $\frac{1}{2500}$ of an inch in diameter, and consist of a soft, granular, colorless substance, containing several nuclei.

The *white corpuscles* possess the power of spontaneous movement, alternately contracting and expanding, throwing out processes of their substance and quickly withdrawing them, thus changing their shape from moment to moment. These movements resemble those of the ameba, and for this reason are termed *ameboid.* The white corpuscles also possess the capability of moving from place to place. In the interior of the vessels they adhere to the inner surface, while the red corpuscles move through the center of the stream.

The white corpuscles are identical with the leukocytes, and are found in milk, lymph, chyle, and other fluids.

Origin of Corpuscles.—The red corpuscles take their origin from the mesoblastic cells in the vascular area of the developing embryo.

In the adult they are produced from colorless, nucleated corpuscles known as *erythroblasts.* The spleen is the organ in which they are finally destroyed.

The white corpuscles originate from the lymphocytes of the adenoid tissue.

COAGULATION OF THE BLOOD.

When blood is withdrawn from the body and allowed to remain at rest, it becomes somewhat thick and viscid in from three to five minutes; this viscidity gradually increases until the entire volume of blood assumes a jelly-like consistence, which process occupies from five to fifteen minutes.

As soon as coagulation is completed, a second process begins, which consists in the contraction of the coagulum and the oozing of a clear, straw-colored liquid,—the *serum,*—which gradually increases in quantity as the *clot* diminishes in size, by contraction, until the separation is completed, which occupies from twelve to twenty-four hours.

The changes in the blood are as follows:

Before coagulation.

Living blood.
- Liq. Sanguinis, or Plasma, consisting of
  - Water.
  - Albumin.
  - Fibrinogen.
  - Salts.
- Corpuscles, red and white.

After coagulation.

Dead blood.
- Crassamentum. Clot or coagulum, containing
  - Fibrin.
  - Corpuscles.
- Serum, containing
  - Water.
  - Albumin.
  - Salts.

The serum, therefore, differs from the liquor sanguinis in not containing fibrin.

In from twelve to twenty-four hours the upper surface of the clot presents a grayish appearance,—the *buffy coat,*—owing to the rapid sinking of the red corpuscles beneath the surface, permitting the fibrin to coagulate without them; this substance then assumes a grayish-yellow tint. Inasmuch as the white corpuscles possess a lighter specific gravity than the red, they do not sink so rapidly, and, becoming entangled in the fibrin, assist in forming the buffy coat. Continued contraction gives a *cupped* appearance to the surface of the clot.

Inflammatory states of the blood produce a marked increase in the buffed and cupped condition, on account of the aggregation of the corpuscles and their tendency to rapid sinking.

Nature of Coagulation.—Coagulated fibrin does not preëxist in the blood, but is formed at the moment blood is withdrawn from the vessels. According to Denis, a liquid substance—*plasmin*—exists in the blood, which, when withdrawn from the circulation, decomposes into *fibrin* and *metalbumin.*

According to Schmidt, fibrin results from the union of *fibrinoplastin* (paraglobulin) and *fibrinogen,* brought about by the presence of a third substance, the fibrin-ferment.

According to Hammersten and others, the fibrin obtained from the blood after coagulation comes from the fibrinogen alone, the conversion being brought about by the presence of a ferment substance, paraglobulin in this case having nothing to do with the change. This view is supported by the fact that the quantity of fibrin obtained from the blood is never greater than the quantity of fibrinogen previously present. The origin of the ferment is obscure, but there is reason to believe that it comes from the injured vascular coats or from the breaking of the white corpuscles.

Conditions Influencing Coagulation.—The process is *retarded* by cold, retention within living vessels, neutral salts in excess, inflammatory conditions of the system, imperfect aëration, exclusion from air, etc.

It is *accelerated* by a temperature of 100° F., contact with air, rough surfaces, and rest.

Blood coagulates in the body after the arrest of the circulation in the course of twelve to twenty-four hours; local arrest of the circulation, from compression or a ligature, will cause coagulation, thus preventing hemorrhages from wounded vessels.

The **composition of the blood** varies in different portions of the body. The *arterial* differs from the *venous,* in being more coagulable; in containing more oxygen and less carbonic acid; in having a bright scarlet color, from the union of oxygen with hemoglobin. the purple hue of venous blood results from the deoxidation of the coloring-matter.

The blood of the *portal vein* differs in constitution, according to different stages of the digestive process; during digestion it is richer in water, albuminous matter, and sugar; occasionally it contains fat; corpuscles are diminished, and there is an absence of biliary substances.

The blood of the *hepatic vein* contains a larger proportion of red and white corpuscles; the sugar is augmented, while albumin, fat and fibrin are diminished.

CIRCULATION OF THE BLOOD.

The **circulatory apparatus** by which the blood is distributed to all portions of the body consists of a central organ,—the heart,—with which is connected a system of closed vessels known as arteries, capillaries, and veins. Within this system the blood is kept, by the action of the heart, in continual movement, distributing nutritive matter to all portions of the body and carrying waste matters from the tissues to the various eliminating organs.

The heart is a hollow, muscular organ, pyramidal in shape, measuring about 5½ inches in length and about 3½ in breadth, weighing from 10 to 12 ounces in the male and from 8 to 10 in the female. Situated in the thoracic cavity, between the lungs, its base is directed upward, backward, and to the right; its apex is directed downward and to the left.

Pericardium.—The heart is surrounded by a closed fibrous membrane called the pericardium. The inner surface of this membrane is lined by a serous membrane, which is also reflected over the surface of the heart; between the two surfaces of the serous membrane is found a small quantity of fluid (the pericardial fluid), which lubricates the surfaces and prevents friction during the movements of the heart. The interior of the heart is also lined by a serous membrane, called the *endocardium.*

Cavities of the Heart.—The general cavity of the heart is subdivided by a longitudinal septum into a right and left half; each of these cavities is in turn subdivided by a transverse constriction into two smaller cavities, which communicate with each other and are known as the auricles and ventricles, the orifice between the auricle and ventricle being known as the *auriculoventricular orifice.* The heart, therefore, consists of four cavities—a right auricle and ventricle and a left auricle and ventricle.

Into the right auricle the two terminal trunks of the venous system—the *superior and inferior venæ cavæ*—empty the venous blood which has been collected from all parts of the system; from the right ventricle arises the *pulmonary artery,* which, passing into the lungs, distributes the blood to the walls of the air-cells of the lungs; into the left auricle empty four *pulmonary veins,* which have collected the blood from the lung capillaries; from the left ventricle springs the *aorta,* the general trunk of the arterial system, the branches of which distribute the blood to the entire system.

The Valves of the Heart.—The valves of the heart are formed by a reduplication of the endocardium strengthened by connective tissue. At the auriculoventricular openings on the right and left sides of the heart, respectively, are found the *tricuspid* and *mitral valves.* The tricuspid valve consists of three, the mitral of two, cusps or segments, which project into the interior of the ventricle when it does not contain blood. At their bases the segments are united so as to form an annular membrane attached to the margin of the orifice. To the free edges of the valves are attached numerous fine threads,—the *chordæ tendineæ,*—which are the tendons of the small papillary muscles springing from the walls of the ventricles.

The Semilunar Valves.—At the openings of the pulmonary artery and the aorta are found three cup-shaped or semilunar valves, the free edges of which are directed away from the interior of the heart. The anatomic arrangement of the valves is such that upon their closure regurgitation of the blood is prevented.

The Course of the Blood through the Heart.—Reference to figure 17 will make it clear that there is a pathway for the blood between the venæ cavæ on the right side and the aorta on the left side by way of the right side of the heart, the cardio-pulmonary vessels and the left side of the heart.

The venous blood flowing towards the heart is emptied by the superior and inferior venæ cavæ into the right auricle from which it passes through the auriculoventricular opening into the right ventricle; thence into and through the pulmonary artery and its branches to the pulmonary capillaries where it is arterialized, *i. e.,* yields up its carbon dioxid and takes on a fresh supply of oxygen—and is changed in color from dark blue to scarlet red. The arterialized blood flowing towards the heart is emptied by the pulmonary veins into the left auricle from which it passes through the auriculoventricular opening into the left ventricle; thence into the

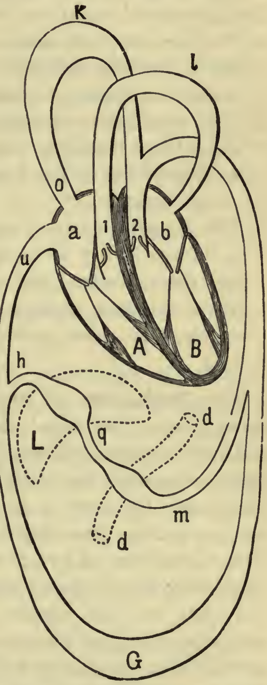


Fig. 17.—Scheme of the Circulation.—(*Landois.*)

a. Right, b. left, auricle. A. Right, B. left ventricle. 1. Pulmonary artery. 2. Aorta. l. Area of pulmonary, K. area of systemic, circulations. o. The superior vena cava. G. Area supplying the inferior vena cava, u. d, d. Intestine. m. Mesenteric artery. q. Portal vein. L. Liver. h. Hepatic vein.

aorta and its branches to the systemic capillaries where it is dearterialized by an opposite exchange of gases, *i. e.*, yields up a portion of its oxygen to, and absorbs carbon dioxid from the tissues, and changes in color from scarlet to dark blue. The venous blood is again returned to the systemic veins to the venæ cavæ.

While there is but one circulation, physiologists frequently divide the circulatory apparatus into—

1. The *systemic circulation,* which includes the movement of the blood from the left side of the heart through the aorta and its branches, through the capillaries and veins, to the right side.
2. The *pulmonary circulation,* which includes the course of the blood from the right side through the pulmonary artery, through the capillaries of the lungs and pulmonary veins, to the left side of the heart.
3. The *portal circulation,* which includes the portal vein. This vein is formed by the union of the radicles of the gastric, mesenteric, and splenic veins, and carries the blood directly into the liver, where the vein divides into a fine capillary plexus, from which the hepatic veins arise; these empty into the ascending vena cava.

The Mechanism of the Heart.—The immediate cause of the movement of the blood through the blood-vessels is the alternate contraction and relaxation of the muscular walls of the heart, and more especially the walls of the ventricles, each of which plays alternately the part of a force pump and to a slight extent of a suction pump. The motive power is furnished by the heart itself. The contraction of any part of the heart is termed the *systole,* the relaxation, the *diastole;* as each side of the heart has two cavities, the walls of which contract and relax in succession, it is customary to speak of an auricular systole and diastole and a ventricular systole and diastole; as the two sides are in the same physiologic relation they contract and relax in the same periods of time.

Movements of the Heart.—At each beat, during the systole, the heart hardens and becomes shortened in its long diameter; its apex is raised up, rotated on its axis from left to right, and thrown forward against the walls of the chest. The *impulse* of the heart, observed about two inches below the nipple and one inch to the sternal side, between the fifth and sixth ribs, is caused mainly by the apex of the heart striking against the chest walls, assisted by the distention of the great vessels about the base of the heart.

The Cardiac Cycle.—The entire period of the heart's pulsation may be divided into three stages, viz.:

1. The auricular contraction and relaxation.
2. The ventricular contraction and relaxation.
3. The pause or period of repose during which both auricles and ventricles are at rest. These three stages constitute collectively a cardiac cycle or a cardiac revolution.

The duration of a cycle, as well as the duration of its three stages, varies in different animals in accordance with the number of cycles which recur in a minute. In human beings in adult life there are about 72 cycles to the minute; the average duration is, therefore, 0.80 sec. From this it follows that the time occupied by any one of the three stages must be extremely short and difficult of determination. From experiments on animals and from observations made on human beings, the following estimates have been made and accepted as approximately correct for human beings:

1. The auricular systole—0.16 sec.; the auricular diastole, 0.64 sec.
2. The ventricular systole—0.32 sec.; the ventricular diastole, 0.48 sec.
3. The period of rest for both auricles and ventricles—0.32 sec.

The Action of the Valves.—The forward movement of the blood is permitted and regurgitation prevented by the alternate action of the auriculoventricular and semilunar valves. As a point of departure for a consideration of the action of these valves and their relation to the systole and diastole of the heart, the close of the ventricular systole may be selected. At this moment, the semilunar valves, which during the systole, are directed outward by the blood current are now suddenly and completely closed by the pressure of the blood in the aorta and pulmonary artery. Regurgitation into the ventricles is thus prevented.

During the ventricular systole, the relaxed auricles are filling with blood. With the ventricular diastole this blood or its equivalent flows into the relaxed and easily distensible ventricles until both auricles and ventricles are nearly filled. The tricuspid and mitral valves which are hanging down into the ventricular cavities, are now floated up by currents of blood welling up behind them until they are nearly closed. The auricles now suddenly contract, forcing their contained volumes into the ventricles which become fully distended.

With the cessation of the auricular systole, the ventricular systole begins. If the blood is not to be returned to the auricles the tricuspid and mitral valves must be instantly and completely closed. This is accomplished by the upward pressure of the blood which brings their free edges in close apposition. Reversal of these valves is prevented by the contraction of the papillary muscles which exert a traction on their under surfaces and edges and hold them steady.

The blood now confined in the ventricles between the closed auriculoventricular and semilunar valves is subjected to pressure on all sides; as the pressure rises proportionately to the vigor of the contraction there comes a moment when the *intra-ventricular pressure* exceeds that in the aorta and pulmonary artery; at once the semilunar valves are thrown open and the blood discharged. Both contraction and outflow continue until the ventricles are practically empty, when relaxation sets in attended by a rapid fall of pressure, under the influence of the positive pressure of the blood in the aorta and pulmonary artery, the semilunar valves are again closed. The accumulation of blood in the auricles, attended by a rise in pressure, again forces the tricuspid and mitral valves open. With these events the cardiac cycle is again completed.

Sounds of the Heart.—If the ear be placed over the cardiac region, two distinct sounds are heard during each revolution of the heart, closely following each other, and which differ in character.

The sound coinciding with the systole in point of time—the *first sound*—is prolonged and dull, and caused by the closure and vibration of the auriculoventricular valves, the contraction of the walls of the ventricles, and the apex-beat; the *second sound,* occurring during the *diastole,* is short and sharp, and caused by the closure of the semilunar valves.

The **frequency of the heart's action** varies at different periods of life, but in the adult male it beats about seventy-two times a minute. It is influenced by age, exercise, posture, digestion, etc.

Age.—Before birth, the *number of pulsations* a minute averages	140
During the first year it diminishes to	128
During the third year it diminishes to	95
From the eighth to the fourteenth year averages	84
In adult life the average is	72

Exercise and *digestion* increase the frequency of the heart's action. *Posture* influences the number of pulsations a minute; in the male, standing, the average is 81; sitting, 71; lying, 66—independent, for the most part, of muscular effort.

The **force exerted by the left ventricle** at each contraction has been estimated at fifty-two pounds. If a tube be inserted into the aorta, the pressure there will be sufficient to support a column of blood nine feet, or a column of mercury six inches, in height, the weight in either case being about four pounds. The estimation of the force which the heart is required to exert to support this column of blood is arrived at by multiplying the pressure in the aorta (four pounds) by the area of the internal surface of the left ventricle (about thirteen inches), each inch of the ventricle being capable of supporting a downward pressure of four pounds.

Work Done by the Heart.—The work done by the heart is estimated by multiplying the amount of blood sent out from the right and left ventricles at each contraction by the pressure of the pulmonary artery and aorta, respectively—*e. g.*, when the right ventricle contracts, it forces out ¼ of a pound of blood, and in so doing must overcome a pressure in the pulmonary artery sufficient to support a column of blood three feet in height; that is, must exert energy sufficient to raise ¼ of a pound 3 feet, or ¼ × 3, or ¾ of a pound 1 foot. When the left ventricle contracts, it sends out ¼ of a pound of blood, and in so doing the left ventricle must overcome a pressure in the aorta sufficient to support a column of blood 9 feet in height; that is, must exert energy sufficient to raise ¼ of a pound 9 feet, or ¼ × 9, or 2¼ pounds 1 foot. Work done is estimated by the amount of energy required to raise a definite weight a definite height; the unit, the foot-pound, being that required to raise 1 pound 1 foot.

The heart, therefore, at each systole exerts energy sufficient to raise 3 foot-pounds, and as it contracts 72 times a minute, it would raise in that time 3 × 72, or 216 foot-pounds; and in one hour 216×60, or 12,960 foot-pounds; and in twenty-four hours 12,960×24, or 311,040 foot-pounds, or 138.5 foot-tons.

The Causation of the Heart Beat.—From the fact that the heart will continue to beat for a variable length of time after removal from the body (the time varying with the species of animal from which it has been obtained) it is evident that the beat is independent of the central nerve system.

The fundamental condition for the continuance of the beat is the maintenance of the irritability. So long as this persists the heart will respond to its appropriate stimulus. The irritability of the heart within the body is dependent on the supply of blood coming through its nutrient vessels or flowing through its cavities. Outside the body, the irritability can be maintained for some hours by similar methods.

The Nature of the Stimulus.—The presence of nerve cells in the walls of the heart, their relation to the muscle cells, the pronounced activity of the sinus of the frog heart where they are very abundant; the feeble activity of the apex where they are absent gave rise to the idea that the stimulus is a nerve impulse rhythmically and automatically discharged by these nerve cells. This view is no longer entertained. It has been demonstrated that portions of the heart muscle, that do not contain nerve cells, will continue to exhibit rhythmic contraction for some hours if supplied with oxygenated and defibrinated blood; that the embryonic heart contracts rhythmically before nerve cells have migrated to its walls.

The stimulus therefore evidently arises within the heart muscle. In other words, it is *myogenic* and not *neurogenic* in origin. The stimulus is now believed to be chemic in character and due to a reaction between the inorganic salts in the muscle cells and those in lymph by which they are surrounded.

The Influence of the Central Nerve System on the Action of the Heart.—Though the heart beat is independent of the central nerve system, it is to a considerable extent modified by it either in the way of *inhibition* or *augmentation*. In all classes of animals the heart not only contains localized collections of nerve cells, but is also connected with the central nerve system by two sets of nerve fibers.

In the frog heart a group of nerve cells is found in the sinus at its junction with the auricle, and known as the crescent or ganglion of Remak; a second group is found at the base of the ventricle on its anterior aspect and known as the ganglion of Bidder; a third group is found in the auricular septum, known as the septal ganglion, or the ganglion of Ludwig. These cells were formerly regarded as the source of the stimuli for the heart's contraction. They are regarded now as trophic in function and influencing in some way the nutrition of the heart muscle.

In the dog and the mammalian heart generally, the nerve cells though present are not arranged in such definite groups, but are distributed in the terminations of the venæ cavæ, pulmonary veins, the walls of the auricles and in the neighborhood of the base of the ventricles.

The nerves which connect the heart with the central nerve system are the pneumogastric, or vagus, and the sympathetic.

The *pneumogastric,* or *vagus* nerve, close to its connection with the medulla oblongata, receives motor nerves from the spinal accessory. It also contains motor fibers, which come direct from the medulla. It then passes down the neck and enters the thorax. Some of its fibers join the cardiac plexus and by this route reach the heart. Experimental evidence indicates that the terminal fibers of the vagus arborize around the nerve cells in the heart wall. *Feeble stimulation* of the trunk of the vagus is followed by a diminution in the rate of the beat; *strong stimulation* is followed by complete cessation or inhibition of the heart beat, the organ coming to rest in the condition of diastole. *Division* of both vagi, in the dog, at a time when the heart is beating normally, is followed by a considerable increase in the frequency of the beat. For these reasons the vagus nerve is said to have an inhibitor or restraining influence on the rate of the heart beat.

The *sympathetic nerves* are derived mainly from the ganglion stellatum. The cells of this ganglion, however, are in relation with nerve fibers which emerge from the spinal cord in the second and third dorsal nerves.

Stimulation of the sympathetic fibers beyond the ganglion stellatum, is followed by an increase in the rate and sometimes by an increase in the force of the heart beat. For this reason the sympathetic is said to exert an accelerator and an augmentor influence on the heart beat.

ARTERIES.

The **arteries** are a series of branching tubes conveying blood to all portions of the body. They are composed of three coats:

1. *External,* formed of areolar and elastic tissue.
2. *Middle,* contains both elastic and muscle fibers, arranged transversely to the long axis of the artery. The elastic tissue is more abundant in the larger vessels, the muscular in the smaller.
3. *Internal,* composed of a thin, homogeneous membrane, covered with a layer of elongated endothelial cells.

The arteries possess both *elasticity* and *contractility.*

The *property of elasticity* allows the arteries already full to accommodate themselves to the incoming amount of blood, and to convert the intermittent acceleration of blood in the large vessels into a steady and continuous stream in the capillaries.

The *contractility* of the smaller vessels equalizes the current of blood, regulates the amount going to each part, and promotes the onward flow of blood.

Blood Pressure.—The immediate cause of the movement of the blood from the beginning of the aorta, through the arteries, capillaries and veins, to the right side of the heart, is a difference of pressure between these two points. A corresponding difference of pressure exists between the beginning of the pulmonary artery and the left side of the heart. To this pressure the term blood pressure is given and may be defined as the pressure exerted laterally by the moving blood stream against the walls of the arteries, capillaries and veins. That there is such a pressure different in amount in each of these three divisions of the vascular apparatus is evident from the results which follow division of an artery or a vein of corresponding size. When an artery is divided the blood spurts from the opening for a considerable distance and with considerable velocity. When a vein is divided the blood as a rule merely wells out of the opening and with but slight momentum. These results indicate that the blood exerts a greater pressure in the arteries than in the veins. Experimentally it has been shown that the pressure is greatest in the aorta, less in the capillaries, and least in the veins. The pressure in the aorta expressed in millimeters of mercury is about 160, in the capillaries 35 to 20, and in the veins from 20 to 0 or less at the terminations of the venæ cavæ.

The causes of the blood pressure are first, the driving power of the heart, and second, the resistance offered by the walls of the blood-vessels to the flow of blood through them. Owing to this resistance, the blood has accumulated and in consequence the whole system has become distended by the lateral pressure. The largest part of the resistance, however, is found at the periphery of the arterial system and is partly the cause of the high pressure in the arteries.

The *arterial pressure* is increased or decreased by influences which act upon the heart or upon this peripheral resistance.

If while the force of the heart remains the same, the rate increases, thus increasing the volume of blood in the arteries, the pressure rises. If the rate remains the same, but the volume of blood discharged increases, the pressure will also rise. If the peripheral resistance is increased by contraction of the arterioles the pressure rapidly rises. On the contrary, a diminution in the rate and force of the heart or a diminution in peripheral resistance by a dilatation of the arteries cause a fall in pressure.

The Pulse.—The pulse may be defined as a periodic expansion and recoil of the arterial system. The expansion is caused by the ejection into the arteries of a volume of blood during the systole; the recoil is due to the reaction of the arterial walls on the blood driving it forward into and through the capillaries, during the diastole.

At the close of the cardiac diastole the arteries are full of blood and considerably distended. During the occurrence of the succeeding systole, the incoming volume of blood is accommodated by a movement forward of a portion of the general blood volume into the capillaries and a further distention of the arteries. The distention naturally begins at the beginning of the aorta. As the blood continues to be discharged from the heart, adjoining segments of the aorta expand in quick succession and by the end of the systole the expansion has travelled over the arterial system as far as the capillaries. This expansion movement which passes over the arterial system in the form of a wave is known as the *pulse wave,* or the *pulse.* It is this alternate expansion and recoil which is perceived by the finger when placed over the course of an artery. The artery best adapted for this purpose is the radial as it passes across the wrist joint.

The **velocity** with which the blood flows in the arteries diminishes from the heart to the capillaries, owing to an enlargement in the united sectional area of the vessels; the velocity increases from the capillaries toward the heart for the opposite reason. The blood moves most rapidly in the large vessels, and especially under the influence of the ventricular systole. From experiments on animals, it has been estimated to move in the carotid of man at the rate of sixteen inches a second, and in the large veins at the rate of four inches a second.

The **caliber of the blood-vessels** is regulated by the *vasomotor* nerves, which have their origin in the gray matter of the medulla oblongata. They issue from the spinal cord through the anterior roots of spinal nerves, pass through the sympathetic ganglia, and ultimately are distributed to the coats of the blood-vessels. They exert at different times a constricting and a dilating action upon the vessels, thus keeping up the arterial tonus and the average blood pressure.

Capillaries.—The capillaries constitute a network of vessels of microscopic size, which distribute the blood to the inmost recesses of the tissues, inosculating with the arteries on the one hand and the veins on the other; they branch and communicate in every possible direction.

The diameter of a capillary vessel varies from $\frac{1}{6000}$ to $\frac{1}{3000}$ of an inch; the walls of these consist of a delicate, homogeneous membrane, $\frac{1}{20000}$ of an inch in thickness, lined by flattened, elongated, endothelial cells, between which, here and there, are observed *stomata.*

The *rate of movement* in the capillary vessels is estimated at one inch in thirty seconds.

In the capillary current the red corpuscles may be seen hurrying down the center of the stream, while the white corpuscles in the still layer adhere to the walls of the vessel, and at times can be seen to pass through the walls of the vessel by ameboid movements.

The *function* of the capillary blood-vessel is to permit of the passage of the nutritive materials of the blood out into the tissue-spaces and the passage of waste products from the tissue-spaces into the blood.

The **passage of the blood** through the capillaries is mainly due to the force of the ventricular systole and the elasticity of the arteries; but it is probably also aided by a power resident in the capillaries themselves, the result of a vital relation between the blood and the tissues.

The **veins** are the vessels which return the blood to the heart; they have their origin in the venous radicles, and as they approach the heart converge to form larger trunks, and terminate finally in the venæ cavæ.

They possess three coats—

1. *External,* made up of areolar tissue.
2. *Middle,* composed of non-striated muscle-fibers; yellow, elastic, and fibrous tissue.

3. *Internal,* an endothelial membrane similar to that of the arteries.

Veins are distinguished by the possession of valves throughout their course, which are arranged in pairs, and formed by a reflection of the internal coat, strengthened by fibrous tissues; they always look toward the heart, and when closed prevent a reflux of blood in the veins. Valves are most numerous in the veins of the extremities, but are entirely absent in many others.

The **onward flow of blood** in the veins is mainly due to the action of the heart, but is assisted by the contraction of the voluntary muscles and the force of respiration.

Muscular contraction, which is intermittent, aids the flow of blood in the veins by compressing them. As regurgitation is prevented by the closure of the valves, the blood is forced onward toward the heart.

Rhythmic movements of veins have been observed in some of the lower animals, aiding the onward current of blood.

During the movement of *inspiration* the thorax is enlarged in all its diameters, and the pressure on its contents at once diminishes. Under these circumstances a suction force is exerted upon the great venous trunks, which causes the blood to flow with increased rapidity and volume toward the heart.

Venous Pressure.—As the force of the heart-beat is nearly expended in driving the blood through the capillaries, the pressure in the venous system is not very marked, not amounting in the jugular vein of a dog to more than $\frac{1}{12}$ that of the carotid artery.

The *time required* for a complete circulation of the blood throughout the vascular system has been estimated to be from twenty to thirty seconds, while for the *entire mass* of blood to pass through the heart fifty-eight pulsations would be required, occupying forty-eight seconds.

The **forces** keeping the blood in circulation are:

1. Action of the heart.
2. Elasticity of the arteries.
3. Capillary force.
4. Contraction of the voluntary muscles upon the veins.
5. Respiratory movements.

RESPIRATION.

Respiration is the function by which oxygen is absorbed into the blood and carbonic acid exhaled. The assimilation of the oxygen and the evolution of carbonic acid takes places in the tissues as a part of the general nutritive process, the blood and respiratory apparatus constituting the media by means of which the interchange of gases is accomplished.

The **respiratory apparatus** consists of a larynx, trachea, and lungs.

The **larynx** is composed of firm cartilages, united by ligaments and muscles. Running anteroposteriorly across the upper opening are four ligamentous bands—the two superior or *false* vocal cords, and the two inferior or *true* vocal cords,—formed by folds of the mucous membrane. They are attached anteriorly to the thyroid cartilages and posteriorly to the arytenoid cartilages, and are capable of being separated by the contraction of the posterior crico-arytenoid muscles, so as to admit the passage of air into and from the lungs.

The **trachea** is a tube from four to five inches in length, ¾ of an inch in diameter, extending from the cricoid cartilage of the larynx to the third dorsal vertebra, where it divides into the right and left bronchi. It is composed of a series of cartilaginous rings, which extend about two thirds around its circumference, the posterior third being occupied by fibrous tissue and non-striated muscle-fibers, which are capable of diminishing its caliber.

The trachea is covered externally by a tough, fibro-elastic membrane, and internally by mucous membrane, lined by columnar, ciliated, epithelial cells. The cilia are always waving from within outward. When the two bronchi enter the lungs, they divide and subdivide into numerous smaller branches, which penetrate the lungs in every direction until they finally terminate in the *pulmonary lobules.*

As the bronchial tubes become smaller their walls become thinner; the cartilaginous rings disappear, but are replaced by irregular angular plates of cartilage; when the tube becomes less than $\frac{1}{50}$ of an inch in diameter, they wholly disappear, and the fibrous and mucous coats blend, forming a delicate elastic membrane, with circular muscle-fibers.

The **lungs** occupy the cavity of the thorax, are conic in shape, of a pink color and a spongy texture. They are composed of a great number of distinct lobules (the *pulmonary lobules*), connected by interlobular connective tissue. These lobules vary in size, are of an oblong shape, and are composed of the ultimate ramifications of the bronchial tubes, within which are contained the *air-vesicles* or *cells*. The walls of the air-vesicles, exceedingly thin and delicate, are lined internally by a layer of tessellated epithelium, externally covered by elastic fibers, which give the lungs their elasticity and distensibility.

The **venous blood** is distributed to the lungs for aëration by the pulmonary artery, the terminal branches of which form a rich plexus of capillary vessels surrounding the air-cells; the air and blood are thus brought into intimate relationship, being separated only by the delicate walls of the air-cells and capillaries.

The thoracic cavity, in which the respiratory organs are lodged, is of a conic shape, having its apex directed upward, its base downward. Its framework is formed posteriorly by the spinal column, anteriorly by the sternum, and laterally by the ribs and costal cartilages. Between and over the ribs lie muscles, fascia, and skin, above, the thorax is completely closed by the structures passing into it and by the cervical fascia and skin; below, it is closed by the diaphragm. It is, therefore, an air-tight cavity.

The Pleura.—Each lung is surrounded by a closed serous membrane (the pleura), one layer of which (the *visceral*) is reflected over the lung; the other (the *parietal*), reflected over the wall of the thorax; between the two layers is a small amount of fluid, which prevents friction during the play of the lungs in respiration.

Owing to the elastic tissue which is present in the lungs, they are very readily distensible; so much so, indeed, that the pressure of the air inside the trachea and lungs is sufficient to distend them until they completely fill all parts of the thoracic cavity not occupied by the heart and great vessels. The elastic tissue endows them not only with distensibility, but also with the power of elastic recoil, by which they are enabled to accommodate themselves to all variations in the size of the thoracic cavity.

When the chest-walls recede, the air within the lungs expands and presses them against the ribs; when the chest-walls contract, the air being driven out, the elastic tissue recoils and the lungs return to their original condition. The movements of the lungs are, therefore, entirely passive.

As the capacity of the chest in a state of rest is greater than the volume of the lungs after they are collapsed, it is quite evident that in the living condition the lungs are distended and in a state of elastic tension, which is greater or less in proportion as the thoracic cavity is increased or diminished in size. The elastic tissue, always on the stretch, is endeavoring to pull the visceral layer of the pleura away from the parietal layer, but is antagonized by the pressure of the air within the air-passages. This condition of things persists as long as the thoracic cavity remains air-tight; but if an opening be made in the thoracic wall, the pressure of the external air, which was previously supported by the practically rigid walls of the thorax, now presses upon the lung with as much force as the air within the lung. The two pressures being neutralized, there is nothing to prevent the elastic tissue from recoiling, driving the air out, and collapsing. The elastic tension of the lungs can be readily measured in man after death by inserting a manometer into the trachea. Upon opening the thorax and allowing the tissue to recoil, the air passes upon the mercury and elevates it, the extent to which it is raised being the index of the pressure. Hutchinson calculated the pressure to be one half pound to the square inch of lung surface.

Respiratory Movements.—The movements of respiration are two, and consist of an alternate dilatation and contraction of the chest, known as inspiration and expiration.

1. *Inspiration* is an active process, the result of the expansion of the thorax, whereby the atmospheric air is introduced into the lungs.
2. *Expiration* is a partially passive process, the result of the recoil of the elastic walls of the thorax, and the recoil of the elastic tissue of the lungs, whereby the intrapulmonary air is expelled.

In **inspiration** the chest is enlarged by an increase in all its diameters—viz.:

1. The *vertical* is increased by the contraction and descent of the diaphragm.
2. The *anteroposterior* and *transverse* diameters are increased by the elevation and rotation of the ribs upon their axes.

In *ordinary tranquil inspiration* the muscles which elevate the ribs and thrust the sternum forward, and so increase the diameters of the chest, are the *external intercostals,* running from above downward and forward; the *sternal portion* of the *internal intercostals,* and the *levatores costarum.*

In the *extraordinary efforts of inspiration* certain auxiliary muscles are brought into play,—viz., the *sternomastoid, pectorales, serratus magnus,*—which increase the capacity of the thorax to its utmost limit.

In **expiration** the diameters of the chest are all diminished—viz.:

1. The *vertical,* by the ascent of the diaphragm.
2. The *anteroposterior,* by a depression of the ribs and sternum.

In *ordinary tranquil expiration* the diameters of the thorax are diminished by the recoil of the elastic tissue of the lungs and the ribs; but in forcible expiration the muscles which depress the ribs and sternum, and thus further diminish the diameter of the chest, are the *internal, intercostals,* the *infracostals,* and the *triangularis sterni.*

In the *extraordinary efforts of expiration* certain auxiliary muscles are brought into play,—viz., the *abdominal* and *sacrolumbalis muscles,* —which diminish the capacity of the thorax to its utmost limit.

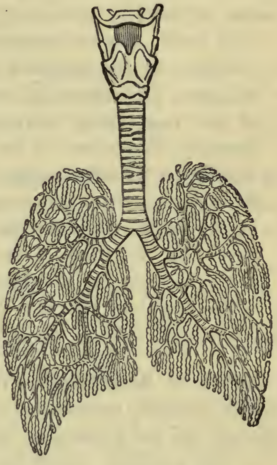


FIG. 18.—DIAGRAM OF THE RESPIRATORY ORGANS.

The windpipe, leading down from the larynx, is seen to branch into two large bronchi, which subdivide after they enter their respective lungs.

Expiration is aided by the recoil of the elastic tissue of the lungs and ribs and by the pressure of the air.

Movements of the Glottis.—At each inspiration the *rima glottidis* is dilated by a separation of the vocal cords, produced by the contraction of the *crico-arytenoid* muscles, so as freely to admit the passage of air into the lungs; in expiration they fall passively together, but do not interfere with the exit of air from the chest.

Nerve Mechanism of Respiration.—The movements of respiratory muscles, though capable of being modified to a certain extent by efforts of the will, are of an automatic character, and called forth by nerve impulses emanating from the medulla oblongata.

The respiratory center, the so-called vital point, generates the nerve impulses, which, traveling outward through the phrenic and intercostal nerves, excite contractions of the diaphragm and intercostal muscles, respectively. This center is for the most part automatic in its action, though it is capable of being modified by impulses reflected to it through various sensor nerves.

This center may be stimulated:

1. *Directly,* by the condition of the blood. An increase of carbonic acid or a diminution of oxygen in the blood causes an acceleration of the respiratory movements; the reverse of these conditions causes a diminution of the respiratory movements.
2. *Indirectly,* by reflex action. The medulla may be excited to action through the pneumogastric nerve, by the presence of carbonic acid in the lungs irritating its terminal filaments; through the fifth nerve, by irritation of the terminal branches; and through the nerves of general sensibility. In either case this center reflects *motor* impulses to the respiratory muscles through the *phrenic, intercostal, inferior laryngeal,* and other nerves.

Types of Respiration.—The *abdominal type* is most marked in young children, irrespective of sex, the respiratory movements being effected by the diaphragm and abdominal muscles,

In the *superior costal type,* exhibited by the adult female, the respiratory movements are more marked in the upper part of the chest, from the first to the seventh ribs, permitting the uterus to ascend in the abdomen during pregnancy without interfering with respiration.

In the *inferior costal type,* manifested by the male, the movements are largely produced by the muscles of the lower portions of the chest, from the seventh rib downward, assisted by the diaphragm.

The respiratory movements vary according to age, sleep, and exercise, being most frequent in early life, but averaging twenty a minute in adult life. They are diminished by sleep and increased by exercise. There are about four pulsations of the heart to each respiratory act.

During both inspiration and expiration *two sounds* are produced: the one, heard in the thorax, in the trachea, and larger bronchial tubes, is *tubular* in character; the other, heard in the substance of the lungs, is *vesicular* in character.

Amount of Air Exchanged in Respiration, and Capacity of Lungs.

The *tidal* or *breathing volume* of air, that which passes in and out of the lungs at each inspiration and expiration, is estimated at from twenty to thirty cubic inches.

The *complemental air* is that amount which can be taken into the lungs by a forced inspiration, in addition to the ordinary tidal volume, and amounts to about 110 cubic inches.

The *reserve air* is that which usually remains in the chest after the ordinary efforts of expiration, but which can be expelled by forcible expiration. The volume of reserve air is about 100 cubic inches.

The *residual air* is that portion which remains in the chest and cannot be expelled after the most forcible expiratory efforts, and which amounts, according to Dr. Hutchinson, to about 100 cubic inches.

The **vital capacity** of the chest indicates the amount of air that can be forcibly expelled from the lungs after the deepest possible inspiration, and is an index of an individual's power of breathing in disease and during prolonged severe exercise. The combined amount of the tidal, the complemental, and the reserve air, 230 cubic inches, represents the vital capacity of an individual five feet seven inches in height. The vital capacity varies chiefly with stature. It is increased eight cubic inches for every inch in height above this standard, and diminishes eight cubic inches for each inch below it.

The **tidal volume** of air is carried only into the trachea and large bronchial tubes by the inspiratory movements. It reaches the deeper portions of the lungs in obedience to the law of diffusion of gases, which is inversely proportionate to the square root of their densities.

The *ciliary action* of the columnar cells lining the broncial tubes also assists in the interchange of air and carbonic acid.

The *entire volume of air* passing in and out of the thorax in twenty-four hours is subject to great variation, but can be readily estimated from the tidal volume and the number of respirations a minute. Assuming that an individual takes into the chest twenty cubic inches at each inspiration, and breathes eighteen times a minute, in twenty-four hours there would pass in and out of the lungs 518,400 cubic inches, or 300 cubic feet.

Chemistry of Respiration.—As the inspired air undergoes a change in composition during its stay in the lungs which renders it unfit for further respiration, it becomes requisite, for the correct understanding of respiration, to ascertain the composition of both inspired and expired air.

Composition of Air.—Chemic analysis has shown that every 100 volumes of air contain 20.81 volumes of oxygen, 79.19 volumes of nitrogen, and 0.03 volume of carbonic acid. Aqueous vapor is also present, though the quantity is variable. The higher the temperature, the greater the amount.

The **changes in the air** effected by respiration are:

Loss of oxygen, to the extent of five cubic inches per 100 of air, or one in twenty.

Gain of carbonic acid, to the extent of 4.66 cubic inches per 100 of air, or 0.93 inch in twenty.

Increase of water-vapor and organic matter.

Elevation of temperature.

Increase, and at times decrease, of nitrogen.

Gain of ammonia.

The *total quantity of oxygen* withdrawn from the air and consumed by the body in twenty-four hours amounts to fifteen cubic feet, and can be readily estimated from the amount consumed at each respiration. Assuming that one cubic inch of oxygen remains in the lungs at each respiration, in one hour there are consumed 1080 cubic inches, and in twenty-four hours 25,920 cubic inches, or fifteen cubic feet, weighing eighteen ounces. To obtain this quantity, 300 cubic feet of air are necessary.

The quantity of oxygen consumed daily is subject to considerable variations. It is *increased* by exercise, digestion, and lowered temperature, and decreased by the opposite conditions.

The *quantity of carbonic acid* exhaled in twenty-four hours varies greatly. It can be estimated in the same way. Assuming that an individual exhales 0.93 + cubic inch at each respiration, in one hour there are eliminated 1008 cubic inches, and in twenty-four 24,192 cubic inches, or fourteen cubic feet, containing seven ounces of pure carbon.

The exhalation of carbonic acid is *increased* by muscular exercise, nitrogenous food, tea, coffee, and rice, age, and by muscular development; *decreased* by a lowering of temperature, repose, gin and brandy, and a dry condition of the air.

As there is always more oxygen consumed than carbonic acid exhaled, and as oxygen unites with carbon to form an equal volume of carbonic acid, it is evident that a certain quantity of oxygen disappears within the body. In all probability it unites with the sulphur hydrogen of the food to form water.

The *amount of water vapor* which passes out of the body with the expired air is estimated at from one to two pounds.

The *organic matter,* though slight in amount, gives the odor to the breath. In a room with defective ventilation the organic matter accumulates and gives rise to headache, nausea, drowsiness, etc. Long-continued breathing of such air produces general ill health. It is not so much the presence of CO_2 in increased amount as the presence of organic matter which necessitates thorough ventilation.

Condition of the Gases in the Blood.

Oxygen is absorbed from the lungs into the arterial blood by the coloring-matter, *hemoglobin,* with which it exists in a state of loose combination, and is disengaged during the process of nutrition.

Carbonic acid, arising in the tissues, is absorbed into the blood in consequence of its alkalinity, where it exists in a state of simple solution and also in a state of feeble combination with the carbonates, soda and potassa, forming the bicarbonates.

Nitrogen is simply held in solution in the plasma.

Exchange of Gases in the Air-cells.—From the difference in tension of the oxygen in the air-cells (27.44 mm. of Hg) and of the oxygen in the venous blood (22 mm. Hg), and from the difference of the carbonic acid tension in the venous blood (41 mm. Hg) and in the air-cells (27 mm. Hg), it might be concluded that the passage of the gases is due solely to pressure. The absorption of oxygen, however, does not follow absolutely the law of pressure; that chemic processes are involved is shown by the union of oxygen with the hemoglobin of the blood corpuscles. The exhalation of CO_2 is also partly a chemic process, as it has been shown that the quantity excreted is greatly increased when oxygen is simultaneously absorbed. Oxygen not only favors the exhalation of loosely combined CO_2, but favors the expulsion of that which can be excreted only by the addition of acids to the blood.

Changes in the Blood during Respiration.

As the blood passes through the lungs it is changed in *color,* from the dark purple of venous blood to the bright red of arterial blood.

The heterogeneous composition of venous blood is exchanged for the uniform composition of the arterial.

It gains oxygen and loses carbonic acid.

Its coagulability is increased. Temperature is diminished.

Asphyxia.—If the supply of oxygen to the lungs be diminished and the carbonic acid retained in the blood, the normal respiratory movements cease and the condition of asphyxia ensues, which soon terminates in death.

The *phenomena* of asphyxia are violent spasmodic action of the respiratory muscles attended by convulsions of the muscles of the extremities, engorgement of the venous system, lividity of the skin, abolition of sensibility and reflex action, and death.

The *cause of death* is a paralysis of the heart from overdistention by blood. The passage of the blood through the capillaries is prevented by contraction of the smaller arteries, from irritation of the vasomotor center. The heart is enfeebled by a want of oxygen and inhibited in its action by the inhibitory centers.

ANIMAL HEAT.

The **functional activity** of all the organs and tissues of the body is attended by the evolution of heat, which is independent, for the most part, of external conditions. Heat is a *necessary condition* for the due performance of all vital actions; although the body constantly loses heat by *radiation* and *evaporation,* it possesses the capability of renewing it and of maintaining it at a fixed standard. The *normal temperature* of the body in the adult, as shown by means of a delicate thermometer placed in the axilla, ranges from 97.25° F. to 99.5° F., though the *mean normal* temperature is estimated by Wunderlich at 98.6° F.

The temperature varies in different portions of the body according to the extent to which oxidation takes place, being highest in the muscles, in the brain, blood, liver, etc.

The **conditions which produce variations** in the normal temperature of the body are: age, period of the day, exercise, food and drink, climate, season, and disease.

Age.—At birth the temperature of the infant is about 1° F. above that of the adult, but in a few hours falls to 95.5° F., to be followed in the course of twenty-four hours by a rise to the normal or a degree beyond. During childhood the temperature approaches that of the adult; in aged persons the temperature remains about the same, though they are not so capable of resisting the depressing effects of external cold as adults. A *diurnal variation* of the temperature occurs from 1.8° F. to 3.7° F. (Jürgensen); the *maximum* occurring late in the afternoon, from 4 to 9 P. M.; the *minimum*, early in the morning, from 1 to 7 A. M.

Exercise.—The temperature is raised from 1° to 2° F. during active contractions of the muscular masses, and is probably due to the increased activity of chemic changes; a rise beyond this point being prevented by its diffusion to the surface, consequent on a more rapid circulation, radiation, more rapid breathing, etc.

Food and Drink.—The ingestion of a hearty meal increases the temperature but slightly; an absence of food, as in starvation, produces a marked decrease. Alcoholic drinks, in large amounts, in persons unaccustomed to their use, cause a depression of the temperature amounting to from 1° to 2° F. Tea causes a slight elevation.

External Temperature.—Long-continued exposure to cold, especially if the body is at rest, diminishes the temperature from 1° to 2° F., while exposure to a great heat slightly increases it.

Disease frequently causes a marked variation in the normal temperature of the body, which rises as high as 107° F. in typhoid fever and 105° F. in pneumonia; in cholera it falls as low as 80° F. Death usually occurs when the heat remains high and persistent, from 106° to 110° F.; the increase of heat in disease is due to excessive production rather than to diminished elimination.

The **source of heat** is to be sought for in the chemic decompositions and hydrations taking place during the general process of nutrition, and in the combustion of the carbonaceous compounds by the oxygen of the inspired air; the amount of its production is in proportion to the activity of the internal changes.

Every contraction of a muscle, every act of secretion, each exhibition of nerve force, is accompanied by a change in the chemic composition of the tissues and an evolution of heat. The reduction of the disintegrated tissues to their simplest form by oxidation, and the combination of the oxygen of the inspired air with the carbon and hydrogen of the blood and tissues, results in the formation of carbonic acid and water and the generation of a great amount of heat.

Certain elements of the food, particularly the *non-nitrogenized* substances, undergo oxidation without taking part in the formation of the tissues, being transformed into carbonic acid and water, and thus increase the sum of heat in the body.

Heat-producing Tissues.—All the tissues of the body add to the general amount of heat, according to the degree of their activity. But special structures, on account of their mass and the large amount of blood they receive, are particularly to be regarded as *heat producers, e. g.:*

1. During mental activity the *brain* receives nearly one fifth of the entire volume of blood, and the venous blood returning from it is charged with waste matters, and its temperature is increased.
2. The *muscular tissue,* on account of the many chemic changes occurring during active contractions, must be regarded as the chief heat-producing tissue.
3. The *secreting glands,* during their functional activity, add largely to the amount of heat.

The entire quantity of heat generated within the body has been demonstrated experimentally to be about 2,300 calories, a calory, or heat unit, being that amount of heat required to raise the temperature of one kilogram of water 2.2 pounds 1° C. This quantity of heat, if not utilized and retained within the body, would elevate its temperature in twenty-four hours about 60° F. That this volume of heat depends very largely upon the oxidation of the food-stuffs can be shown experimentally.

The normal temperature of the body is maintained by a constant expenditure of the heat in several directions:

1. In warming the food, drink, and air that are consumed in twenty-four hours. For this purpose about 157 heat units are required.
2. In evaporating water from the skin and lungs, 619 heat units being utilized for this purpose.
3. In radiation and conduction. By these processes the body loses at least fifty per cent. of its heat, or 1,156 heat units.
4. In the production of work; the work of the circulatory, respiratory, muscular, and nervous apparatus being performed by the transformation of 369 heat units into units of work.

The *nervous system* influences the production of heat in a part by increasing the amount of blood passing through it by its action upon the vasomotor nerves. Whether there exists a special heat-center has not been satisfactorily determined, though this is probable.

SECRETION.

The **process of secretion** consists in the separation of materials from the blood which are either to be again utilized to fulfil some special purpose in the economy, or are to be removed from the body as excrementitious matter; in the former case they constitute the *secretions,* in the latter, the *excretions.*

The *materials* which enter into the composition of the *secretions* are derived from the nutritive principles of the blood, and require special organs—*e. g.,* gastric glands, mammary glands, etc.—for their proper elaboration.

The *materials* which compose the *excretions* preëxist in the blood, and are the results of the activities of the nutritive process; if retained within the body, they exert a deleterious influence upon the composition of the blood.

Destruction of a secreting gland abolishes the secretion peculiar to it, and it can not be formed by any other gland; but among the excreting organs there exists a complementary relation, so that if the function of one organ be interfered with, another performs it to a certain extent.

Classification of the Secretions.

PERMANENT FLUIDS.

Serous fluids.
Synovial fluid.
Aqueous humor of the eye.
Vitreous humor of the eye.
Fluid of the labyrinth of the internal ear.
Cerebro-spinal fluid.

TRANSITORY FLUIDS.

Mucus.
Sebaceous matter.
Cerumen (external meatus).
Meibomian fluid.
Milk and colostrum.
Tears.
Saliva.
Gastric juice.
Pancreatic juice.
Secretion from Brunner's glands.
Secretion from Lieberkühn's glands.
Secretions from follicles of the large intestine.
Bile (also an excretion).

EXCRETIONS.

Perspiration and the secretion of the axillary glands.
Urine.
Bile (also a secretion).

FLUIDS CONTAINING FORMED ANATOMIC ELEMENTS.

Seminal fluid, containing spermatozoids.

Fluid of the Graafian follicles.

The **essential apparatus** for secretion is a delicate, homogeneous, structureless *membrane,* on one side of which, in close contact, is a capillary plexus of *blood-vessels,* and on the other side a layer of *cells* the physiologic function of which varies in different situations.

Secreting organs may be divided into *membranes* and *glands.*

Serous membranes usually exist as closed sacs, the inner surfaces of which are covered by pale, nucleated epithelium, containing a small amount of secretion.

The serous membranes are the *pleura, peritoneum, pericardium, synovial sacs,* etc.

The *serous fluids* are of a pale amber color, somewhat viscid, alkaline, coagulable by heat, and resemble the serum of the blood; their *amount* is but small. The pleural fluid varies from four to seven drams; the peritoneal from one to four ounces; the pericardial from one to three drams.

The *synovial fluid* is colorless, alkaline, and extremely viscid, from the presence of *synovin.*

The *function* of serous fluids is to moisten the opposing surfaces, so as to prevent friction during the play of the viscera.

The *mucous membranes* are soft and velvety in character, and line the cavities and passages leading to the exterior of the body—*e. g.,* the *gastro-intestinal, pulmonary* and *genito-urinary.* They consist of a primary basement membrane covered with epithelial cells, which in some situations are tessellated, in others, columnar.

Mucus is a pale, semitransparent, alkaline fluid, containing epithelial cells and leukocytes. It is composed, chemically, of water, an albuminous principle (*mucin*), and mineral salts; the principal varieties are nasal, bronchial, vaginal, and urinary.

Secreting glands are formed of the same elements as the secreting membranes, but instead of presenting flat surfaces, are involuted, forming tubules, which may be *simple follicles—e. g.,* mucous, uterine, or intestinal; or *compound follicles—e. g.,* gastric glands, mammary glands, or *racemose glands—e. g.,* salivary glands and pancreas. They are composed of a basement membrane, enveloped by a plexus of blood-vessels, and are lined by epithelial and *true secreting cells,* which in different glands possess the capability of elaborating elements characteristic of their secretions.

In the production of the secretion two essentially different processes are concerned:

1. *Chemic.*—The formation and elaboration of the characteristic organic ingredients of the secreted fluids—*e. g.*, pepsin, pancreatin —take place during the intervals of glandular activity, as a part of the general function of nutrition. They are formed by the cells lining the glands, and can often be seen in their interior with the aid of the microscope—*e. g.*, bile in the liver cells, fat in the cells of the mammary gland.
2. *Physical.*—Consisting of a transudation of water and mineral salts from the blood into the interior of the gland.

During the intervals of glandular activity only that amount of blood passes through the gland sufficient for proper nutrition; when the gland begins to secrete, under the influence of an appropriate stimulus, the blood-vessels dilate and the quantity of blood becomes greatly increased beyond that flowing to the gland during its repose.

Under these conditions a transudation of water and salt takes place, washing out the characteristic ingredients, which are discharged by the gland ducts. The *discharge* of the secretions is intermittent; they are retained in the glands until they receive the appropriate stimulus, when they pass into the larger ducts by the *vis a tergo,* and are then discharged by the contraction of the muscular walls of the ducts.

The *activity* of glandular secretion is hastened by an increase in the blood-pressure and retarded by a diminution.

The *nerve centers* in the medulla oblongata influence secretion:

1. By increasing or diminishing the amount of blood entering a gland.
2. By exerting a direct influence upon the secreting cells themselves, the centers being excited by reflex irritation, mental emotion, etc.

MAMMARY GLANDS.

The **mammary glands,** which secrete the milk, are two more or less hemispheric organs, situated in the human female on the anterior surface of the thorax. Though rudimentary in childhood, they gradually increase in size as the young female approaches puberty.

The gland presents at its convexity a small prominence of skin (the nipple), which is surrounded by a circular area of pigmented skin (the areola). The gland proper is covered by a layer of adipose tissue anteriorly and is attached posteriorly to the pectoral muscles by a meshwork of fibrous tissue. During utero-gestation the mammary glands become larger, firmer, and more lobulated; the areola darkens and the veins become more prominent. At the period of lactation the gland is the seat of active histologic and physiologic changes, correlated with the production of milk. At the close of lactation the glands diminish in size, undergo involution, and gradually return to their original non-secreting condition.

Structure of the Mammary Gland.—The mammary gland consists of an aggregation of some fifteen or twenty lobes, each of which is surrounded by a framework of fibrous tissue. The lobe is provided with an excretory duct, which, as it approaches the base of the nipple, expands to form a sinus or reservoir, beyond which it opens by a narrowed orifice on the surface of the nipple. On tracing the duct into a lobe, it is found to divide and subdivide, and finally to terminate in lobules or acini. Each acinus consists of a basement membrane, lined by low polyhedral cells. Externally it is surrounded by connective tissue supporting blood-vessels, lymphatics and nerves.

MILK.

Milk is an opaque, bluish-white fluid, almost inodorous, of a sweet taste, an alkaline reaction, and a specific gravity of 1025 to 1040. When examined microscopically it is seen to consist of a clear fluid (the *milk-plasma*), holding in suspension an enormous number of small, highly refractive oil-globules, which measure, on an average, $\frac{1}{10000}$ of an inch in diameter. Each globule is supposed by some observers to be surrounded by a thin, albuminous envelope, which enables it to maintain the discrete form. *The quantity* of milk secreted daily by the human female averages about two and a half pints. The milk of all the mammalia consists of all the different classes of nutritive principles, though in varying proportions. The relative proportions in which these constituents exist are shown in the following table of analyses:

COMPOSITION OF MILK.

IN 100 PARTS.	HUMAN.	COW.	GOAT.	ASS.	SHEEP.	MARE.
Water.	88.00	86.87	87.54	91.57	82.27	88.80
Caseinogen.	2.40	3.98	3.00	1.09	6.10	2.19
Lactalbumin.	0.57	0.77	0.62	0.70	1.00	0.42
Fat.	2.90	3.50	4.20	1.02	5.30	2.50
Lactose.	5.87	4.00	4.00	5.50	4.20	5.50
Salts.	0.16	0.17	0.56	0.42	1.00	0.50

Caseinogen is the chief proteid constituent of milk, and is held in solution by the presence of calcium phosphate. On the addition of acetic acid or of sodium chlorid up to the point of saturation, the caseinogen is *precipitated* as such, and may be collected by appropriate chemic methods. When taken into the stomach caseinogen is *coagulated*—that is, it is separated into casein or tyrein and a small quantity of a new soluble proteid. The ferment which induces this change is known as rennin. The presence of calcium phosphate is necessary for this coagulation.

The **fat** of milk is more or less solid at ordinary temperatures. It is a composition of olein, palmitin, and stearin, with a small quantity of butyrin and caproin. When milk is allowed to stand for some time the fat-globules rise to the surface and form a thick layer, known as cream. When subjected to the churning process, the fat globules run together and form a cohesive mass—the butter.

Lactose is the particular form of sugar characteristic of milk. It belongs to the saccharose group and has the following composition: $C_{12}H_{22}O_{11}$. In the presence of the bacillus acidi lactici the lactose is decomposed into lactic acid and carbon dioxid, the former of which will cause a coagulation of the caseinogen.

Mechanism of Secretion.—During the time of lactation the mammary gland exhibits periods of secretory activity which alternate with periods of rest. Coincidentally with these periods, certain histologic changes take place in the secreting structures of the gland. At the close of a period of active secretion each acinus presents the following features: the epithelial cells are short, cubic, nucleated, and border a relatively wide lumen in which is to be found a variable quantity of non-discharged milk. After the gland has rested for some time, active metabolism again begins. The epithelial cells grow and elongate; the nucleus divides into two or three new nuclei, and at the same time the cell becomes constricted; the inner-portion is detached and is discharged into the lumen. Coincidentally with these changes oil-globules make their appearance in the cell protoplasm, some of which are discharged separately into the lumen, while others remain for a time associated with the detached cell. From these histologic changes it would appear that the caseinogen and the fat-globules are metabolic products of the cell protoplasm, and not derived directly from the blood. That lactose has a similar origin appears certain from the fact that it is formed independently of carbohydrate food. The water and inorganic salts are doubtless secreted by a mechanism similar to that of all other secreting glands.

VASCULAR OR DUCTLESS GLANDS.

INTERNAL SECRETIONS.

The metabolism of the body generally, as well as that of individual organs, has been shown to be related not only to the physiologic activity of such organs as the liver and pancreas, but also to the activity of the so-called vascular or ductless glands. The influence of the pancreas in regulating the production of glycogen by the liver, and the influence of the liver in the maintenance of the general metabolism through the production of glycogen and the formation or urea, are now established facts. That the vascular or ductless glands to an equal extent, though perhaps in a different way, assist in the maintenance of physiologic processes, appears certain from the results of animal experimentation. The explanation given, and generally accepted at the present time, for the influence of these glands is that they produce specific substances, which are poured into the blood or lymph and carried direct to the tissues, to the activities of which they appear to be essential; for without these substances the nutrition of the tissues declines and in a short time a fatal termination ensues.

Inasmuch as these partly unknown substances are formed by cell activity and are poured into the interstices of the tissues, they have been termed "internal secretions." Though the term internal secretions is applicable to all substances which arise in consequence of tissue metabolism, and which after being poured into the blood, influence in varying degrees and ways physiological processes, yet the term in this connection will be applied only to the secretions of the thyroid gland, hypophysis cerebri, and adrenal bodies.

Thyroid Gland.—The thyroid gland or body consists of two lobes situated on the lateral aspect of the upper part of the trachea. Each lobe is pyriform in shape, the base being directed downward and on a level with the fifth or sixth tracheal ring. The lobe is about 50 mm. in length, 20 mm. in breadth, and 25 mm. in thickness. As a rule, the lobes are united by a narrow band or isthmus of the same tissue. In color the gland is reddish, and it is abundantly supplied with blood-vessels and lymphatics.

Microscopic examination shows that the thyroid consists of an enormous number of closed sacs or vesicles, variable in size, the largest not measuring more than 0.1 mm. in diameter. Each sac is composed of a thin homogeneous membrane lined by cuboid epithelium. The interior of the sac in adult life contains a transparent viscid fluid, containing albumin and termed "colloid" substance. Externally, the sacs are surrounded by a plexus of capillary blood-vessels and lymphatics. The individual sacs are united and supported by connective tissue, which forms, in addition, a covering for the entire gland.

Function of the Thyroid.—The knowledge at present possessed as to the function of the thyroid gland, especially in mammals, is the outcome of a study of the effects which follow its arrest of development in the child, its degeneration in the adult, its extirpation in the human being as well as in animals. The results, however, which follow its extirpation are not always uniform in all animals; sufficient reasons for which lack of uniformity can not always be assigned.

Cretinism, a condition characterized by a want of physical and mental development, is associated with, if not directly dependent on, a congenital absence or an arrested development of the thyroid, either at the time of birth or during the early years of childhood.

Myxedema, a condition of the skin in which there is a hyperplasia of the connective tissue, of an embryonic type, rich in mucin, is generally regarded as one of the effects of degenerative processes in the thyroid. Partly in consequence of this change in the skin the face becomes broader, swollen, and flattened, giving rise to a loss of expression. At the same time the mind becomes dull, clouded, even approximating the idiotic type. This supposed infiltration of the skin with mucin was termed myxedema by Ord, who at the same time associated it with a change in the structure of the thyroid as a result of which it became functionally useless.

Extirpation of the thyroid, for relief from symptoms due to grave pathologic changes, has been followed in human beings by symptoms similar to those of myxedema. To this condition the terms operative myxedema and cachexia strumipriva have been applied.

After the publication of the history of the myxedema which followed surgical removal of the thyroid, Schiff, in 1887, repeated his earlier experiments on dogs, and found again that removal of the thyroid was speedily followed by tremors, convulsions, and death. Similar experiments were made by Horsley on monkeys, with results which resembled those characteristic of myxedema. Among the symptoms which developed within a few days after the removal of the gland may be mentioned loss of appetite; fibrillar contractions of muscles; tremors; spasms; mucinoid degeneration of the skin, giving rise to puffiness of the eyelids and face and to a swollen condition of the abdomen; hebetude of mind, frequently terminating in idiocy; fall of blood-pressure; dyspnea; albuminuria; atrophy of the tissues, followed by death of the animal in the course of from five to eight weeks. The complexus of symptoms observed in monkeys was divided by Horsley into three stages: viz., the neurotic, the mucinoid, and the atrophic. It is evident that the presence of the thyroid is essential to the normal activity of the tissues generally. As to the manner in which it exerts its favorable influence, there is some difference of opinion. The view that the gland removes from the blood certain toxic bodies, rendering them innocuous, and thus preserving the body from a species of auto-intoxication, is gradually yielding to the more probable view that the epithelium is engaged in the secretion of a specific material, which finds its way into the blood or lymph and in some unknown way influences favorably tissue metabolism. This view of the function of the thyroid is supported by the fact that successful grafting of a portion of the thyroid beneath the skin or in the abdominal cavity will prevent the usual symptoms which follow thyroidectomy. The same result is obtained by the intravenous injection of thyroid juice or by the administration of the raw gland. It was shown by Murray that myxedematous patients could be benefited, and even cured, by feeding them with fresh thyroids or even with the dry extract.

The chemic features of the material secreted and obtained from the structures of the thyroid indicate that it is a complex proteid containing iodin, which, under the influence of various reagents, undergoes cleavage, giving rise to a non-proteid residue, which carries with it the iodin and phosphorus. The amount of iodin in the thyroid varies from 0.33 to 1 milligram for each gram of tissue. To this compound the term *thyroiodin* has been given. The administration of this compound produces effects similar to those which follow the therapeutic administration of the fresh thyroid itself: viz., a diminution of all myxedematous symptoms. In normal states of the body, thyroiodin influences very actively the general metabolism. It gives rise to a decomposition of fats and proteids and to a decline in body-weight. In large doses it may produce toxic symptoms: *e. g.*, increased cardiac action, vertigo, and glycosuria.

The Hypophysis Cerebri.—This is a small body lodged in the sella turcica of the sphenoid bone. In consists of an anterior lobe, somewhat red in color, and a posterior lobe, yellowish-gray in color. The former is much the larger and partly embraces the latter. The anterior lobe is developed from an invagination of the epiblast of the mouth cavity, and consists of distinct gland tissue. The posterior lobe is an outgrowth from the brain, and is connected with the infundibulum by a short stalk. It has been suggested that the term infundibular body be reserved for the posterior lobe. This distinction appears to be desirable, inasmuch as in their origin and structure they are separate and distinct bodies.

Removal of the hypophysis cerebri, or the pituitary body, is always followed by a fatal result, preceded by symptoms not unlike those which follow removal of the thyroid: viz., anorexia, tremors, spasms, etc. Degeneration of the hypophysis has been found in connection with a hypertrophic condition of the bones of the face and extremities, to which the term acromegalia has been given.

Intravenous injection of an extract of the hypophysis increases the force of the heart-beat without any change in its frequency, and causes a rise of blood-pressure from a stimulation of the arterioles (Schäfer and Oliver). The material secreted by the hypophysis has not been isolated, hence its chemic features are unknown. After its formation it probably passes through a system of ducts into the cerebrospinal fluid, after which it influences the metabolism of the nervous and osseous tissues as well as the force of the heart muscle.

An extract of the hypophysis itself exerts no appreciable effect on the blood-pressure or on the rate of the heart-beat, nor does it influence the circulatory and respiratory organs (Howell). An extract of the infundibular body intravenously injected, however, gives rise to increased blood-pressure and to a slowing of the heart-beat.

Adrenal Bodies, or Suprarenal Capsules.—These are two flattened bodies, somewhat crescentic or triangular in shape, situated each upon the upper extremity of the corresponding kidney, and held in place by connective tissue. They measure about 40 mm. in height, 30 mm. in breadth, and from 6 to 8 mm. in thickness. The weight of each is about 4 gm.

Function of the Adrenal Bodies.—It was observed by Addison that a profound disturbance of the nutrition, characterized by a bronze-like discoloration of the skin and mucous membranes of the mouth, extreme muscular weakness, and profound anemia, was associated with, if not dependent on, pathologic conditions of the suprarenal glands. In the progress of the disease the asthenia gradually increases, the heart becomes weak, the pulse small, soft, and feeble, indicating a general loss of tone of the muscular and vascular apparatus. Death ensues from paralysis of the respiratory muscles. The essential nature of the lesion which gives rise to these symptoms has not been determined.

Removal of these bodies from various animals is invariably and in a short time followed by death, preceded by some of the symptoms characteristic of Addison's disease. Their development, however, was more acute. From the fact that animals so promptly die from extirpation of these bodies, and the further fact that the blood of such animals is toxic to those the subjects of recent extirpation, but not to normal animals, the conclusion was drawn that the function of the adrenal bodies was to remove from the blood some toxic material the product of muscle metabolism. Its accumulation after extirpation gives rise to death through auto-intoxication.

On the supposition that the adrenals might secrete and pour into the blood a specific material which favorably influences general metabolism, Schäfer and Oliver injected hypodermically glycerin and water extracts, and observed at once an increased activity of the heart-beats and of the respiratory movements. The effects, however, were only transitory. When these extracts are injected into the veins directly, there follows in a short time a cessation of the auricular contraction of the heart, though the ventricular contraction continues with an independent rhythm. If the vagi are cut previous to the injection or if the inhibition is removed by atropin, the rapidity and vigor of both auricles and ventricles are increased. Whether the inhibitory influence is removed or not, there is a marked increase in the blood-pressure, though it is greater in the former than in the latter instance. This is attributed to a direct stimulation and contraction of the muscle-fibers of the arterioles themselves, and not to vaso-motor influences, as it occurs also after division of the cord and destruction of the bulb. The contraction of the arterioles is quite general, as shown by plethysmographic studies of the limbs, spleen, kidney, etc. Applied locally to the mucous membranes, the adrenal extract produces contraction of the blood-vessels and pallor. The skeletal muscles are affected by the extract very much as they are by veratrin. The duration of a single contraction is very much prolonged, especially in the phase of relaxation or of decreasing energy.

It is evident from these experiments that the adrenal bodies are engaged in elaborating and pouring into the blood a specific material which stimulates to increased activity the muscle-fibers of the heart and arteries, and thus assists in maintaining the normal blood-pressure as well as the tonicity of the skeletal muscles. The active principle of this gland has been isolated by Abel and termed *epinephrin.*

EXCRETION.

The **principal excrementitious fluids** discharged from the body are the urine, perspiration, and bile; they hold in solution principles of waste which are generated during the activity of the nutritive process and are the ultimate forms to which the organic constituents are reduced in the body. They also contain inorganic salts.

The **urinary apparatus** consists of the kidneys, ureters, and bladder.

KIDNEYS.

The **kidneys** are the organs for the secretion of urine; they resemble a bean in shape, are from four to five inches in length, two in. breadth, and weigh from four to six ounces.

They are situated in the lumbar region, one on each side of the vertebral column behind the peritoneum, and extend from the eleventh rib to the crest of the ilium; the anterior surface is convex, the posterior surface concave, the latter presenting a deep notch, the *hilus*.

The kidney is surrounded by thin, smooth membrane composed of white fibrous and yellow elastic tissue; though it is attached to the surface of the kidney by minute processes of connective tissue, it can be readily torn away. The substance of the kidney is dense, but friable.

Upon making a longitudinal section of the kidney it will be observed that the *hilus* extends into the interior of the organ and expands to form a cavity known as the *sinus*. This cavity is occupied by the upper, dilated portion of the ureter, the interior of which forms the *pelvis*. The ureter subdivides into several portions, which ultimately give origin to a number of smaller tubes, termed *calyces,* which receive the apices of the pyramids.

The **parenchyma of the kidney** consists of two portions—viz.:

1. *An internal* or *medullary portion,* consisting of a series of *pyramids* or *cones,* some twelve or fifteen in number. They present a distinctly striated appearance, a condition due to the straight direction of the tubules and blood-vessels.
2. *An external* or *cortical portion,* consisting of a delicate matrix containing an immense number of tubules having a markedly con-

voluted appearance. Throughout its structure are found numerous small ovoid bodies, termed *Malpighian corpuscles.*

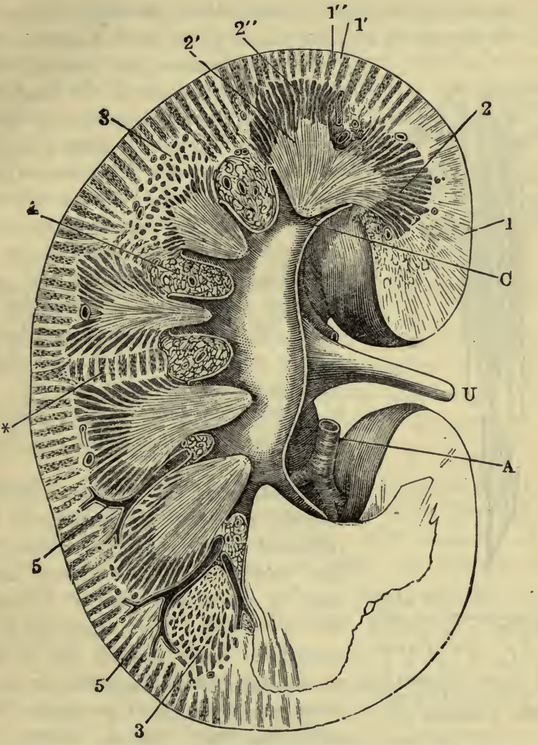


Fig. 19.—Longitudinal Section through the Kidney, the Pelvis of the Kidney, and a number of Renal Calyces.—(*Tyson, after Henle.*)

A. Branch of the renal artery. U. Ureter. C. Renal calyx. 1. Cortex. 1'. Medullary rays. 1''. Labyrinth, or cortex proper. 2. Medulla. 2'. Papillary portion of medulla, or medulla proper. 2''. Border layer of the medulla. 3, 3. Transverse section through the axes of the tubules of the border layer. 4. Fat of the renal sinus. 5, 5. Arterial branches. * Transversely coursing medulla rays.

The Uriniferous Tubules.—The kidney is a compound, tubular gland composed of microscopic tubules whose function it is to secrete from the blood those waste products which collectively constitute the urine. If the apex of each pyramid be examined with a lens, it will present a number of small orifices, which are the beginnings of the uriniferous tubules. From this point the tubules pass outward in a straight but somewhat divergent manner toward the cortex, giving off at acute angles a number of branches (Fig. 20). From the apex to the base of the pyramids they are known as the tubules of Bellini. In the cortical portion of the kidney each tubule becomes enlarged and twisted, and after pursuing an extremely convoluted course, turns backward into the medullary portion for some distance, forming the descending limb of Henle's loop: it then turns upon itself, forming the ascending limb of the loop, reënters the cortex, again expands, and finally terminates in a spheric enlargement known as *Müller's* or *Bowman's capsule.* Within this capsule is contained a small tuft of blood-vessels, constituting the *glomerulus,* or *Malpighian corpuscle.*

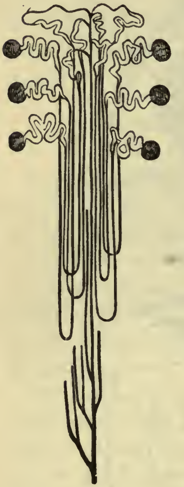


Fig. 20.—Diagrammatic Exposition of the Method in which the Uriniferous Tubes Unite to Form Primitive Cones.—(*Tyson, after Ludwig.*)

Structure of the Tubules.—Each tubule consists of a basement membrane lined by epithelial cells throughout its entire extent. The tubule and its contained epithelium vary in shape and size in different parts of its course. The termination of the convoluted tube consists of a little sac or capsule, which is ovoid in shape and measures about $\frac{1}{200}$ of an inch. This capsule is lined by a layer of flattened epithelial cells, which is also reflected over the surface of the glomerulus. During the periods of secretory activity the blood-vessels of the glomerulus become filled with blood, so that the cavity of the sac is almost obliterated; after secretory activity the blood-vessels contract and the sac-cavity becomes enlarged. In that portion of the tubule lying between the capsule and Henle's loop the epithelial cells are cuboid in shape; in Henle's loop they are flattened, while in the remainder of the tubule they are cuboid and columnar.

Blood-vessels of the Kidney.—The *renal artery* is of large size and enters the organ at the hilum; it divides into several large branches, which penetrate the substance of the kidney between the pyramids, at the base of which they form an anastomosing plexus, which completely surrounds them. From this plexus vessels follow the straight tubes toward the apex, while others, entering the cortical portion, divide into small twigs, which enter the Malpighian body and form a mass of convoluted vessels, the *glomerulus.* After circulating through the Malpighian tuft, the blood is gathered together by two or three small veins, which again subdivide and form a fine capillary plexus, which envelops the convoluted tubules; from this plexus the veins converge to form the emulgent vein, which empties into the vena cava.

The **nerves of the kidney** follow the course of the blood-vessels and are derived from the renal plexus.

The **ureter** is a membranous tube, situated behind the peritoneum, about the diameter of a goose-quill, eighteen inches in length, and extends from the pelvis of the kidney to the base of the bladder, which it perforates in an oblique direction. It is composed of three coats: fibrous, muscular, and mucous.

The **bladder** is a reservoir for the temporary reception of the urine prior to its expulsion from the body; when fully distended it is ovoid in shape, and holds about *one pint.* It is composed of four coats: *serous, muscular* (the fibers of which are arranged longitudinally and circularly), *areolar,* and *mucous.* The orifice of the bladder is controlled by the *sphincter vesicæ,* a muscular band about ½ of an inch in width.

As soon as the urine is formed it passes through the *tubuli uriniferi* into the pelvis ,and thence through the ureters into the bladder, which it enters at an irregular rate. Shortly after a meal, after the ingestion of large quantities of fluid, and after exercise, the urine flows into the bladder quite rapidly, while it is reduced to a few drops during the intervals of digestion. It is prevented from regurgitating into the ureters by the oblique direction they take between the mucous and muscular coats.

Nerve Mechanism of Urination.—When the urine has passed into the bladder, it is there retained by the sphincter vesicæ muscle, kept in a state of chronic contraction by the action of a nerve center in the lumbar region of the spinal cord. This center can be inhibited and the sphincter relaxed, either *reflexly,* by impressions coming through sensory nerves from the mucous membrane of the bladder, or *directly,* by a voluntary impulse descending the spinal cord. When the desire to urinate is experienced, impressions made upon the vesical sensory nerves are carried to the centers governing the *sphincter* and *detrusor urinæ* muscles and to the brain. If now the act of urination is to take place, a voluntary impulse originating in the brain passes down the spinal cord and still further inhibits the sphincter vesicæ center, with the effect of relaxing the muscle and of stimulating the center governing the detrusor muscle, with the effect of contracting the muscle and expelling the urine. If the act is to be suppressed, voluntary impulses inhibit the *detrusor* center and possibly stimulate the *sphincter* center.

The *genitospinal* center controlling these movements is situated in that portion of the spinal cord corresponding to the origin of the third, fourth, and fifth sacral nerves.

URINE.

Normal urine is of a pale yellow or amber color, perfectly transparent, with an aromatic odor, an acid reaction, a specific gravity of 1020, and a temperature when first discharged of 100° F.

The *color* varies considerably in health, from a pale yellow to a brown hue, owing to the presence of the coloring-matter, *urobilin* or *urochrome.*

The *transparency* is diminished by the presence of mucus, the calcium and magnesium phosphates, and the mixed urates.

The *reaction* of the urine is acid, owing to the presence of acid phosphate of sodium. The degree of acidity, however, varies at different periods of the day. Urine passed in the morning is strongly acid, while that passed during and after digestion, especially if the food is largely vegetable in character, is either neutral or alkaline.

The *specific gravity* varies from 1015 to 1025.

The *quantity* of urine excreted in twenty-four hours is between forty and fifty fluidounces, but ranges above and below this standard.

The *odor* is characteristic, and caused by the presence of taurylic and phenylic acids, but is influenced by vegetable foods and other substances eliminated by the kidneys.

COMPOSITION OF URINE.

Water	967.0
Urea	14.230
Other nitrogenized crystalline bodies, uric acid, principally in the form of alkaline urates, Creatin, creatinin, xanthin, hypoxanthin, Hippuric acid, leucin, tyrosin, taurin, cystin, all in small amounts, and not constant, Mucus and pigment,	10.635
Salts	
Inorganic: principally sodium and potassium sulphates, phosphates, and chlorids, with magnesium and calcium phosphates, traces of silicates and chlorids, *Organic:* lactates, hippurates, acetates, formates, which appear only occasionally,	8.135
Sugar	a trace
Gases (nitrogen and carbonic acid principally).	
	1,000.000

The **average quantity** of the principal constituents excreted in twenty-four hours is as follows:

Water	52.0	fluidounces.
Urea	512.4	grains.
Uric acid	8.5	"
Phosphoric acid	45.0	"
Sulphuric acid	31.11	"
Inorganic salts	323.25	"
Lime and magnesia	6.5	"

To determine the amount of solid matters in any given amount of urine, multiply the last two figures of the specific gravity by the coefficient of Haeser, 2.33—*e. g.*, in 1,000 grains of urine having a specific gravity 1022, there are contained $22 \times 2.33 = 51.26$ grains of solid matter.

Organic Constituents of Urine.—Urea is one of the most important of the organic constituents of the urine, and is present to the extent of from 2.5 to 3.2 per cent. Urea is a colorless, neutral substance, crystallizing in four-sided prisms terminated by oblique surfaces. When crystallization is caused to take place rapidly, the crystals take the form of long, silky needles. Urea is soluble in water and alcohol; when subjected to prolonged boiling, it is decomposed, giving rise to carbonate of ammonia. In the alkaline fermentation of urine, urea takes up two molecules of water with the production of carbonate of ammonia.

The *average amount* of urea excreted daily has been estimated at about 500 grains. As urea is one of the principal products of the breaking up of the albuminous compounds within the body, it is quite evident that the quantity produced and eliminated in twenty-four hours will be *increased* by any increase in the amount of albuminous food consumed, or by a rapid destruction of albuminous tissues, as is observed in various pathologic states, inanition, febrile conditions, fevers, etc. A farinaceous or vegetable diet will diminish the urea production nearly one half.

Muscular exercise when the nutrition of the body is in a state of equilibrium does not seem to increase the quantity of urea.

Seat of Urea Formation.—As to the seat of urea formation, little is positively known. It is quite certain that it preëxists in the blood and is merely excreted by the kidneys. It is not produced in muscles, as even after prolonged exercise hardly a trace of urea is to be found in them. Experimental and pathologic facts point to the liver as the probable organ engaged in urea formation. Acute yellow atrophy of the liver, suppurative diseases of the liver, diminish almost entirely the production of urea.

Uric acid is also a constant ingredient of the urine and is closely allied to urea. It is a nitrogen-holding compound, carrying out of the body a portion of the nitrogen. The amount eliminated daily varies from five to ten grains. Uric acid is a colorless crystal belonging to the rhombic system. It is insoluble in water, and if eliminated in excessive amounts, it is deposited as a "brick-red" sediment in the urine. It is doubtful if uric acid exists in a free state, being combined for the most part with sodium and potassium bases forming urates. It is to be regarded as one of the terminal products of the decomposition of nucleic acid which in turn is derived from nuclein, a constituent of cell nuclei.

Hippuric acid is found very generally in urine, though it is present only in small amounts. It is increased by a diet of asparagus, cranberries, plums, and by the administration of benzoic and cinnamic acids. It is probably formed in the kidney.

Kreatinin resembles the kreatin derived from muscles. It is a colorless crystal, belonging to the rhombic system. Its origin is unknown, though it is largely increased in amount by albuminous food. About fifteen grains are excreted daily.

Xanthin, hypo-xanthin, and **guanin** are also constituents of urine. They are nitrogenized compounds and are also terminal products of nucleic acid.

Urobilin, the coloring-matter of the urine, is a derivative of the bile pigments. It is particularly abundant in febrile conditions, giving to the urine its reddish-yellow color.

Inorganic Constituents of Urine.—Earthy Phosphate. *Phosphoric acid* in combination with magnesium and calcium is excreted daily to the extent of from fifteen to thirty grains. The phosphates are insoluble in water, but are held in solution in the urine by its acid ingredients, alkalinity of the urine being attended with a copious precipitation of the phosphates. Mental work increases the amount of phosphoric acid excreted, a condition caused by increased metabolism of the nervous tissue.

Sulphuric acid in combination with sodium and potassium constitutes the sulphates, of which about thirty grains are excreted daily. Sulphuric acid results largely from the decomposition of albuminous food and from increased destruction of animal tissues.

The *gases* of urine are carbonic acid and nitrogen.

Mechanism of Urinary Secretion.—As the kidney anatomically presents an apparatus for filtration (the Malpighian bodies) and an apparatus for secretion (the epithelial cells of the urinary tubules), it might be inferred that the elimination of the constituents of the urine is accomplished by the twofold process of *filtration* and *secretion;* that the water and highly diffusible inorganic salts simply pass by diffusion through the walls of the blood-vessels of the glomerulus into the capsule of Müller, while the urea and remaining organic constituents are removed by true secretory action of the renal epithelium. Modern experimentation supports this view of renal action.

The secretion of urine, is, therefore, partly *physical* and partly *vital.*

The *filtration* of urinary constituents from the glomerulus into Müller's capsule depends largely upon the blood-pressure and the rapidity of blood flow in the renal artery and glomerulus. Among the influences which increase the pressure and velocity may be mentioned increased frequency and force of the heart's action, contraction of the capillary vessels of the body generally, dilatation of the renal artery, and increase in the volume of the blood.

The reverse conditions lower the blood-pressure and diminish the secretion of urine.

The fact that organic matters are eliminated by the *secretory activity* of the renal epithelium seems to be well established by modern experiments. These substances, removed from the blood in the secondary capillary plexus of blood-vessels, by a true selective action of the epithelium, are dissolved and washed toward the pelves by the liquid coming from the capsules.

The blood-supply to the kidney is regulated by the nervous system. If the renal nerves be divided, the renal artery dilates and a copious flow of urine takes place. If the peripheral ends of the same nerves be stimulated, the artery contracts and the urinary flow ceases. The same is true of the splanchnic nerves, through which the vaso-motor nerves coming from the medulla oblongata and spinal cord pass to the renal plexus.

LIVER.

The **liver** is a highly vascular, conglomerate gland, appended to the alimentary canal. It is the largest gland in the body, weighing about four and one half pounds; it is situated in the right hypochondriac region, and is retained in position by five ligaments, four of which are formed by duplicatures of the peritoneal investment.

The *proper coat* of the liver is a thin but firm fibrous membrane, closely adherent to the surface of the organ, which it penetrates at the transverse fissure, and follows the vessels in their ramifications through its substance, constituting *Glissŏn's capsule.*

Structure of the Liver.—The liver is made up of a large number of small bodies (the *lobules*), rounded or ovoid in shape, measuring

$\frac{1}{25}$ of an inch in diameter, separated by a space in which are situated blood-vessels, nerves, hepatic ducts, and lymphatics.

The **lobules** are composed of cells, which, when examined microscopically, exhibit a rounded or polygonal shape, and measure, on the average, $\frac{1}{1000}$ of an inch in diameter; they possess one, and sometimes two, nuclei; they also contain globules of fat, pigment matter, and animal starch. The cells constitute the *secreting* structure of the liver, and are the *true hepatic cells.*

The **blood-vessels** which enter the liver are:

1. The *portal vein,* made up of the *gastric, splenic,* and *superior* and *inferior mesenteric veins.*
2. The *hepatic artery,* a branch of the celiac axis.

Both the portal vein and the hepatic artery are invested by a sheath of areolar tissue.

The vessels which leave the liver are the *hepatic veins,* originating in its interior, collecting the blood distributed by the portal vein and hepatic artery, and conducting it to the *ascending vena cava.*

Distribution of Vessels.—The *portal vein* and the *hepatic artery,* upon entering the liver, penetrate its substance, divide into smaller and smaller branches, occupy the spaces between the lobules, completely surrounding and limiting them, and constitute the *interlobular* vessels. The *hepatic artery,* in its course, gives off branches to the walls of the portal vein and Glisson's capsule, and finally empties into the small branches of the *portal vein* in the interlobular spaces.

The *interlobular vessels* form a rich plexus around the lobules, from which branches pass to neighboring lobules and enter their substance, where they form a very fine network of capillary vessels, ramifying over the hepatic cells, in which the various functions of the liver are performed. The blood is then collected by small veins, converging toward the center of the lobule, to form the *intralobular vein,* which runs through its long axis and empties into the *sublobular vein.* The *hepatic veins* are formed by the union of the sublobular veins, and carry the blood to the ascending vena cava; their walls are thin and adherent to the substance of the hepatic tissue.

The **hepatic ducts** or **bile capillaries** originate within the lobules, in a very fine plexus lying between the hepatic cells; whether the smallest vessels have distinct membranous walls, or whether they originate in the spaces between the cells by open orifices, has not been satisfactorily determined.

The *bile-channels* empty into the interlobular ducts, which measure about $\frac{1}{2000}$ of an inch in diameter and are composed of a thin, homogeneous membrane lined by flattened epithelial cells.

As the interlobular bile-ducts unite to form large trunks, they receive an external coat of fibrous tissue, which strengthens their walls; they finally unite to form one large duct (the *hepatic duct*), which joins the *cystic duct;* the union of the two forms the *ductus communis choledochus,* which is about three inches in length, the size of a goose-quill, and opens into the duodenum.

The **gall-bladder** is a pear-shaped sac, about four inches in length, situated in a fossa on the under surface of the liver. It is a reservoir for the bile, and is capable of holding about one ounce and a half of fluid. It is composed of three coats:

1. Serous, a reflection of the peritoneum.
2. Fibrous and muscular.
3. Mucous.

Functions of the Liver.—The liver is a complex organ having a variety of relations to the general processes of the body. While its physiologic actions are not yet wholly understood, it may be said that it—

1. Secretes bile.
2. Forms glycogen.
3. Assists in the formation of urea and allied products.

The Secretion of Bile.—The characteristic constituents of the bile do not preëxist in the blood, but are formed in the interior of the liver cells of materials derived from the venous and arterial blood. The hepatic cells, absorbing these materials, elaborate them into bile-elements, and in so doing undergo histologic changes similar to those exhibited by other secretory glands. The bile once formed, it passes into the mouths of the bile capillaries, near the periphery of the lobules. Under the influence of the *vis a tergo* of the new-formed bile it flows from the smaller into the large bile-ducts, and finally empties into the intestine, or is regurgitated into the gall-bladder, where it is stored up until it is required for the digestive process in the small intestine. The study of the secretion of bile by means of biliary fistulæ reveals the fact that the secretion is continuous and not intermittent; that the hepatic cells are constantly pouring bile into the ducts, which convey it into the gall-bladder. As this fluid is required only during intestinal digestion, it is only then that the walls of the gall-bladder contract and discharge it into the intestine.

The flow of bile from the liver cells into the gall-bladder is accomplished by the inspiratory movements of the diaphragm, and by the contraction of the muscle-fibers of the biliary ducts, as well as the *vis a tergo* of new-formed bile. Any obstacle to the outflow of bile into the intestine leaps to an accumulation within the bile-ducts. The pressure within the ducts increasing beyond that of the blood within the capillaries, a reabsorption of biliary matters by the lymphatics takes place, giving rise to the phenomena of jaundice.

The **bile** is both a *secretion* and an *excretion;* it contains new constituents, which are formed only in the substance of the liver, and are destined to play an important part ultimately in nutrition; it contains also waste ingredients, which are discharged into the intestinal canal and eliminated from the body.

Glycogenic Function.—In addition to the preceding function, Bernard, in 1848, demonstrated the fact that the liver, during life, normally produces a sugar-forming substance, analogous in its chemic composition to starch, which he terms glycogen; also that, when the liver is removed from the body, and its blood-vessels are thoroughly washed out, after a few hours sugar again makes its appearance in abundance.

It can be shown to exist in the blood of the hepatic vein as well as in a decoction of the liver substance by means of either Trommer's or Fehling's test, even when the blood of the portal vein does not contain a trace of sugar.

Origin and Destination of Glycogen.—Glycogen appears to be formed *de novo* in the liver cells, from materials derived from the food, whether the diet be animal or vegetable, though a larger percentage is formed when the animal is fed on starchy and saccharin than when fed on animal food. The *dextrose,* which is one of the products of digestion, is absorbed by the blood-vessels and carried directly into the liver; as it does not appear in the urine, as it would if injected at once into the general circulation, it is probable that it is detained in the liver, dehydrated, and stored up as *glycogen.* The change is shown by the following formula:

$$\underset{\text{Dextrose.}}{C_6H_{12}O_6} - \underset{\text{Water.}}{H_2O} = \underset{\text{Glycogen.}}{C_6H_{10}O_5}.$$

The glycogen thus formed is stored up in the hepatic cells for the future requirements of the system. When it is carried from the liver, it is again transformed into *dextrose* by the agency of a ferment. Glycogen does not undergo oxidation in the blood; this process takes place in the tissues, particularly in the muscles, where it generates heat and contributes to the development of muscular force.

Glycogen, when obtained from the liver, is an amorphous, starch-like substance, of a white color, tasteless and colorless, and soluble in water; by boiling with dilute acids, or subjected to the action of an animal ferment, it is easily converted into *dextrose*. When an excess of sugar is generated by the liver, dextrose can be found not only in the blood of the hepatic vein, but also in other portions of the body; under these circumstances it is eliminated by the kidneys, appearing in the urine, constituting the condition of *glycosuria*.

Formation of Urea.—The liver is now regarded by many physiologists as the principal organ concerned in urea formation. The liver normally contains a certain amount of urea; and if blood be passed through the excised liver of an animal which has been in full digestion when killed, a large amount of urea is obtained. The clinical evidence proves that in destructive diseases of the liver substance there is at once a falling-off in urea elimination. Various drugs which stimulate liver action increase the amount of urea in the urine.

Influence of the Nerve System.—The nervous system directly controls the functional activity of the liver, and more especially its glycogenic function. It was discovered by Bernard that puncture of the medulla oblongata is followed by so enormous a production of sugar that it is at once excreted by the kidneys, giving rise to diabetic or saccharine urine. This part of the medulla is, however, the vaso-motor center for the blood-vessels of the liver. Destruction of this center, or injury to the vaso-motor nerves emanating from it in any part of their course, is followed at once by dilatation of the hepatic blood-vessels, slowing of the blood-current, a profound disturbance of the normal relation existing between the blood and liver-cells, and a production of sugar. Many of the hepatic vaso-motor nerves may be traced down the cord as far as the lumbar region, while others leave the cord high up in the neck and enter the cervical ganglia of the sympathetic, and so reach the liver. Injury to the sympathetic ganglia is often followed by diabetes. Peripheral stimulation of various nerves—*e. g.,* sciatic, pneumogastric, depressor nerve,—as well as the direct action of many drugs, impair or depress the hepatic vaso-motor center and so give rise to diabetes.

SKIN.

The **skin,** the external investment of the body, is a most complex and important structure, serving—

1. As a *protective covering.*
2. As an organ for *tactile sensibility.*
3. As an organ for the *elimination of excrementitious matters.*

The **amount of skin** investing the body of a man of average size is about twenty feet, and varies in thickness, in different situations, from $\frac{1}{8}$ to $\frac{1}{100}$ of an inch.

The skin consists of two principal layers—viz., a deeper portion, the *corium,* and a superficial portion, the *epidermis.*

The **corium,** or **cutis vera,** may be subdivided into a *reticulated* and a *papillary* layer. The *former* is composed of white fibrous tissue, non-striated muscle-fibers, and elastic tissue, interwoven in every direction, forming an areolar network, in the meshes of which are deposited masses of fat, and a structureless, amorphous matter; the *latter* is formed mainly of club-shaped elevations or projections of the amorphous matter, constituting the *papillæ;* they are most abundant and well developed upon the palms of the hands and upon the soles of the feet; they average $\frac{1}{100}$ of an inch in length, and may be simple or compound; they are well supplied with nerves, blood-vessels, and lymphatics.

The **epidermis,** or **scarf skin,** is an extravascular structure, a product of the true skin, and is composed of several layers of cells. It may be divided into two layers: the *rete mucosum,* or the *Malpighian layer,* and the *horny* or *corneous.*

The *former* is closely adherent to the papillary layer of the true skin, and is composed of large, nucleated cells, the lowest layer of which, the "prickle cells," contains pigment-granules, which give to the skin its varying tints in different individuals and in different races of men; the more superficial cells are large, colorless, and semi-transparent. The *latter,* the corneous layer, is composed of flattened cells, which, from their exposure to the atmosphere, are hard and horny in texture; it varies in thickness from $\frac{1}{8}$ of an inch on the palms of the hands and soles of the feet to $\frac{1}{900}$ of an inch in the external auditory canal.

APPENDAGES OF THE SKIN.

Hairs are found in almost all portions of the body, and can be divided into—

1. Long, soft hairs, on the head.
2. Short, stiff hairs, along the edges of the eyelids and nostrils.
3. Soft, downy hairs on the general cutaneous surface.

They consist of a *root* and a *shaft.* The latter is oval in shape and about $\frac{1}{400}$ of an inch in diameter; it consists of fibrous tissue, covered externally by a layer of imbricated cells, and internally by cells containing granular and pigment material.

The *root* of the hair is embedded in the hair-follicle, formed by a tubular depression of the skin, extending nearly through to the subcutaneous tissue; its walls are formed by the layers of the corium, covered by epidermic cells. At the bottom of the follicle is a papillary projection of amorphous matter, corresponding to a papilla of the true skin, containing blood-vessels and nerves, upon which the hair-root rests. The investments of the hair-roots are formed of epithelial cells, constituting the *internal* and *external* root-sheaths.

The hair protects the head from the heat of the sun and from the cold, retains the heat of the body, prevents the entrance of foreign matter into the lungs, nose, ears, etc. The *color* is due to pigment matter. In old age the hair becomes more or less whitened.

The **sebaceous glands,** embedded in the true skin, are simple and compound racemose glands, opening, by a common excretory duct, upon the surface of the epidermis or into the hair-follicle. They are found in all portions of the body, most abundantly in the face, and are formed by a delicate, structureless membrane, lined by flattened polyhedral cells. The sebaceous glands secrete a peculiar oily matter (the *sebum*), by which the skin is lubricated and the hairs are softened; it is quite abundant in the region of the nose and forehead, which often presents a greasy, glistening appearance; it consists of water, mineral salts, fatty globules, and epithelial cells.

The *vernix caseosa,* which frequently covers the surface of the fetus at birth, consists of the residue of the sebaceous matter, containing epithelial cells and fatty matters; it seems to keep the skin soft and supple, and guards it from the effects of the long-continued action of the amniotic water.

The **sudoriparous glands** excrete the sweat. They consist of a mass or coil of a tubular gland duct, situated in the derma and in the subcutaneous tissue, average $\frac{1}{75}$ of an inch in diameter, and are surrounded by a rich plexus of capillary blood-vessels. From this coil the duct passes in a straight direction up through the skin to the epidermis, where it makes a few spiral turns and opens obliquely upon the surface. The sweat-glands consist of a delicate homogeneous membrane lined by epithelial cells, whose function is to extract from the blood the elements existing in the perspiration.

The glands are very abundant all over the cutaneous surface—as many as 3528 to the square inch, according to Erasmus Wilson.

The **perspiration** is an excrementitious fluid, clear, colorless, almost odorless, slightly acid in reaction, with a specific gravity of 1003 to 1004.

The **total quantity** of perspiration excreted daily has been estimated at about two pounds, though the amount varies with the nature of the food and drink, exercise, external temperature, season, etc.

The elimination of the sweat is not intermittent, but continuous; it takes place so gradually that as fast as it is formed it passes off by evaporation as *insensible* perspiration. Under exposure to great heat and exercise the evaporation is not sufficiently rapid, and it appears as *sensible* perspiration.

COMPOSITION OF SWEAT.

Water	995.573
Urea	0.043
Fatty matters	0.014
Alkaline lactates	0.317
Alkaline sudorates	1.562
Inorganic salts	2.491
	1,000.000

Urea is a constant ingredient.

Carbonic acid is also exhaled from the skin, the amount being about $\frac{1}{200}$ of that from the lungs.

Perspiration regulates the temperature and removes waste matters from the blood; it is so important that if elimination be prevented, death occurs in a short time.

Influence of the Nerve System.—The secretion of sweat is regulated by the nerve system. Here, as in the secreting glands, the fluid is formed from material in the lymph-spaces surrounding the gland. Two sets of nerves are concerned—viz., *vasomotor,* regulating the blood-supply; and *secretor,* stimulating the activities of the gland cells. Generally the two conditions, increased blood flow and increased glandular action, coexist. At times profuse clammy perspiration occurs, with diminished blood flow.

The dominating sweat-center is located in the medulla, though subordinate centers are present in the cord. The secretory fibers reach the perspiratory glands of the head and face through the cervical sympathetic; of the arms, through the thoracic sympathetic, ulnar, and radial nerves; of the leg, through the abdominal sympathetic and sciatic nerves.

The sweat-center is excited to action by mental emotions, increased temperature of blood circulating in the medulla and cord, increased venosity of blood, many drugs, rise of external temperature, exercise, etc.

THE CENTRAL ORGANS OF THE NERVE SYSTEM AND THEIR NERVES.

The central organs of the nerve system are the encephalon and the spinal cord, lodged within the cavity of the cranium and the cavity of the spinal column respectively. The general shape of these two portions of the nerve system correspond with that of the cavities in which they are contained. The encephalon is broad and ovoid, the spinal cord is narrow and elongated.

The **encephalon** is subdivided by deep fissures into four distinct, though closely related portions: viz., (1) the cerebrum, the large ovoid mass occupying the entire upper part of the cranial cavity; (2) the cerebellum, the wedge-shaped portion placed beneath the posterior part of the cerebrum and lodged within the cerebellar fossæ; (3) the isthmus of the encephalon, the more or less pyramidal-shaped portion connecting the cerebrum and cerebellum with each other and both with (4) the medulla oblongata.

The **spinal cord** is narrow and cylindric in shape. It occupies the spinal canal as far down as the second or third lumbar vertebra.

The **nerves** in relation with the central organs of the nerve system are the encephalic or cranial and the spinal nerves.

The encephalic nerves are twelve in number on each side of the median line. Because of the fact that they pass through foramina in the walls of the cranium they are usually termed cranial nerves.

The spinal nerves are thirty-one in number on each side of the cord.

The cranial and spinal nerves are ultimately distributed to all the structures of the body—*e. g.*, the general periphery, and for this reason they are collectively known as the peripheral organs of the nerve system.

The central organs of the nerve system are supported and protected by three membranes named, in their order from without inward, as the dura mater, the arachnoid and the pia mater.

The **dura mater,** the outermost of the three, is a tough membrane, composed of white fibrous tissue arranged in bundles, which interlace in every direction. In the cranial cavity it lines the inner surface of the bones, and is attached to the edge of the foramen magnum; it sends processes inward, forming the falx cerebri, falx cerebelli, and tentorium cerebelli, supporting and protecting parts of the brain. In the spinal canal it loosely invests the cord, and is separated from the walls of the canal by areolar tissue.

The **arachnoid,** the middle membrane, is a delicate serous structure which envelops the brain and cord, forming the *visceral layer,* and is then reflected to the inner surface of the dura mater, forming the *parietal layer.* Between the two layers there is a small quantity of fluid which prevents friction by lubricating the two surfaces.

The **pia mater,** the most internal of the three, composed of areolar tissue and blood-vessels, covers the entire surface of the brain and cord, to which it is closely adherent, dipping down between the convolutions and fissures. It is exceedingly vascular, sending small blood-vessels some distance into the brain and cord.

The **cerebro-spinal fluid** occupies the *subarachnoid space* and the general ventricular cavities of the brain, which communicate by an opening (the foramen of Magendie) in the pia mater, at the lower portion of the fourth ventricle. This fluid is clear, transparent, alkaline, possesses a salty taste and has a low specific gravity; it is composed largely of water, traces of albumin, glucose, and mineral salts. The quantity is estimated from two to four fluidounces.

The *function* of the cerebro-spinal fluid is to protect the brain and cord by preventing concussion from without; by being easily displaced into the spinal canal, prevents undue pressure and insufficiency of blood to the brain.

SPINAL CORD.

The **spinal cord** varies from sixteen to eighteen inches in length; is ½ of an inch in thickness, weighs 1½ ounces, and extends from the atlas to the second lumbar vertebra, terminating in the *filum terminale.* It is cylindric in shape, and presents an enlargement in the lower cervical and lower dorsal regions, corresponding to the origin of the nerves which are distributed to the upper and lower extremities. The cord is divided into two lateral halves by the anterior and posterior fissures. It is composed of both *white* or *fibrous* and *gray* or *vesicular* matter, the former occupying the exterior of the cord, the latter the interior, where it is arranged in the form of two crescents, one in each lateral half, united by the central mass, the *gray commissure;* the white matter being united in front by the *white commissure.*

Structure of the Gray Matter.—The gray matter is arranged in the form of two crescents, united by a commissural band, forming a figure resembling the letter H. Each crescent presents an *anterior* and a *posterior* horn. The center of the commissure presents a canal which extends from the fourth ventricle downward to the filum terminale. The anterior horn is short and broad and does not extend to the surface. The posterior horn is narrow and elongated and extends quite to the surface. It is covered and capped by the *substantia gelatinosa.* The gray matter consists primarily of a framework of fine connective tissue, supporting blood-vessels, lymphatics, medullated and non-medullated nerve-fibers, and groups of nerve-cells.

The **nerve-cells** are arranged in groups, which extend for some distance throughout the cord, forming columns more or less continuous. The first group is situated in the anterior horn, the cells of which are large, multipolar, and connected with the anterior roots of the spinal nerves, and are supposed to be motor in function. The second group is situated in the posterior horn, the cells of which are spindle-shaped, and from their relation to the posterior roots are supposed to be sensory in function. The third group is situated in the lateral aspect of the gray matter, and is quite separate and distinct, except in the lumbar and cervical enlargements, where it blends with those of the anterior horn. A fourth group is situated at the inner base of the posterior horn; it begins about the seventh or eighth cervical nerve and extends downward to the second or third lumbar, being most prominent in the dorsal region. This column is known as Clark's vesicular column.

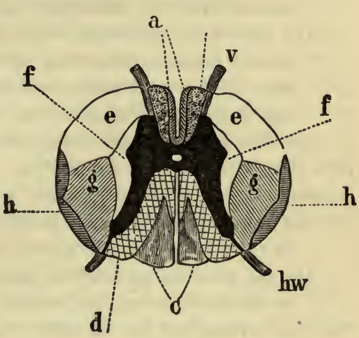


Fig. 21.—Scheme of the Conducting Path in the Spinal Cord at the Third Dorsal Nerve.—(*Landois.*)

The black part is the gray matter. v. Anterior, hw, posterior, root. a. Direct, and g, g, crossed, pyramidal tracts. b. Anterior column, ground bundle. c. Goll's column. d. Postero-external column. e, e, and f, f. Mixed lateral paths. h, h. Direct cerebellar tracts.

Structure of the White Matter.—The white matter surrounding each lateral half of the cord is made up of nerve fibers, some of which are continuations of the nerves which enter the cord, while others are derived from different sources. It is subdivided into—

1. An *anterior* column, comprising that portion between the anterior roots and the anterior fissure, which is again subdivided into two parts:
    - (*a*) An *inner* portion, bordering the anterior median fissure, the *direct pyramidal tract*, or column of Türck; it contains motor fibers which do not decussate, and which extend as far down as the middle of the dorsal region.
    - (*b*) An *outer* portion, surrounding the anterior cornua, known as the *anterior root zone*, composed of short, longitudinal fibers which serve to connect different segments of the spinal cord.
2. A *lateral* column, the portion between the anterior and posterior roots, which is divisible into—

(*a*) The *crossed pyramidal tract,* occupying the posterior portion of the lateral column, and containing all those fibers of the motor tract which have decussated at the medulla oblongata; it is composed of longitudinally running fibers, which are connected with the multipolar nerve-cells of the anterior cornua.

(*b*) The *direct cerebellar tract,* situated upon the surface of the lateral column, consisting of longitudinal fibers which terminate in the cerebellum; it first appears in the lumbar region, and increases in thickness as it passes upward.

(*c*) The *anterior tract,* lying just posterior to the anterior cornua.

3. A *posterior* column, the portion included between the posterior roots and the posterior fissure, also divisible into two portions:
   (*a*) An *inner* portion, the *postero-internal column,* or the column of Goll, bordering the posterior median fissure, and
   (*b*) An *external* portion, the *postero-external* column, the column of Burdach, lying just behind the posterior roots.

The two portions of the posterior column are composed of long and short commissural fibers, which connect different segments of the spinal cord.

The Relation of the Spinal Nerves to the Spinal Cord.—The spinal nerves present near the spinal cord two divisions which from their connection with the anterior or ventral and the posterior or dorsal surfaces are known as the anterior or ventral and posterior or dorsal roots. The ventral roots are composed of nerve-fibers which have their origin in the nerve-cells in the anterior horns of the gray matter. The dorsal roots are composed of nerve-fibers which have their origin in the nerve-cells in the spinal ganglia. After entering the cord some of the posterior or dorsal root-fibers arborize around nerve-cells in the gray matter at the same level; others pass obliquely upward through the posterior white columns as far as the nucleus gracilis and the nucleus cuneatus around the nerve-cells of which they terminate.

FUNCTIONS OF THE SPINAL CORD.

The spinal cord, by virtue of its contained nerve-cells and nerve-fibers, may be regarded as composed of—

1. Independent nerve centers each of which has a special function; and—
2. Of conducting paths by which these centers are brought into

relation with one another and with the cerebrum and its subordinate or underlying parts.

1. As an Independent Nerve Center.

The spinal cord, by virtue of its contained nerve-cells, is capable of transforming afferent nerve impulses arriving through the afferent nerves into efferent impulses, which are reflected outward through efferent nerves to muscles, producing motion; to glands, exciting secretion; to blood-vessels, changing their caliber. All such actions taking place independent of either sensation or volition are termed reflex actions. The mechanism involved in every reflex action consists of a sentient surface, an afferent nerve, an emissive center, an efferent nerve, and a responsive organ, muscle, gland, or blood-vessels.

The *reflex excitability* of the cord may be—

1. *Increased* by disease of the lateral columns, by the administration of strychnin, and, in frogs, by a separation of cord from the brain, the latter apparently exerting an inhibitory influence over the former and depressing its reflex activity.
2. *Decreased* by destructive lesion of the cord—*e. g.*, locomotor ataxia, atrophy of the anterior cornua—the administration of various drugs, and, in the frog, by irritation of certain regions of the brain. When the cerebrum alone is removed and the optic lobes are stimulated, the time elapsing between the application of an irritant to a sensor surface and the resulting movement will be considerably prolonged, the optic lobes (Setschenow's center) apparently generating impulses which, descending the cord, retard its reflex movement.

Classification of Reflex Movements (Küss).—They may be divided into four groups, according to the route through which the afferent and efferent impulses pass:

1. Those normal reflex acts (*e. g.*, deglutition, coughing, sneezing, walking, etc.) and pathologic reflex acts (*e. g.*, tetanus, vomiting, epilepsy) which take place both afferently and efferently through spinal nerves.
2. Reflex acts which take place in an afferent direction through a cerebro-spinal sensor nerve, and in an efferent direction through a sympathetic motor nerve—*e. g.*, the normal reflex acts, which give rise to most of the secretions, pallor of the skin and blushing, certain movements of the iris, certain modifications in the

beat of the heart; the pathologic reflexes, which, on account of the difficulty in explaining their production, are termed *metastatic*—*e. g.,* ophthalmia, coryza, orchitis, which depend on a reflex hyperemia; amaurosis, paralysis, paraplegia, etc., due to a reflex anemia.

3. Reflex movements in which the afferent impulse passes through a sympathetic nerve, and the efferent through a cerebro-spinal nerve; most of these phenomena are pathological—*e. g.,* convulsions from intestinal irritation produced by the presence of worms, eclampsia, hysteria, etc.
4. Reflex actions in which both the afferent and efferent impulses pass through filaments of the sympathetic nervous system—*e. g.,* those obscure reflex actions which preside over the secretions of the intestinal fluids, which unite the phenomena of the generative organs, the dilatation of the pupils from intestinal irritation (worms), and many pathologic phenomena.

Laws of Reflex Action (Pflüger).

1. *Law of Unilaterality.*—If a feeble irritation be applied to one or more sensory nerves, movement takes place usually on one side only, and that the same side as the irritation.
2. *Law of Symmetry.*—If the irritation becomes sufficiently intense, motor reaction is manifested, in addition, in corresponding muscles of the opposite side of the body.
3. *Law of Intensity.*—Reflex movements are usually more intense on the side of the irritation; at times the movements of the opposite side equal them in intensity, but they are usually less pronounced.
4. *Law of Radiation.*—If the excitation still continues to increase, it is propagated upward, and motor reaction takes place through centrifugal nerves coming from segments of the cord higher up.
5. *Law of Generalization.*—When the irritation becomes very intense, it is propagated in the medulla oblongata; motor reaction then becomes general, and it is propagated up and down the cord, so that all the muscles of the body are thrown into action, the medulla oblongata acting as a focus whence radiate all reflex movements.

Special Reflex Movements.

Among the reflexes connected with the more superficial portions of the body there are some which are so frequently either exaggerated or diminished in pathologic lesions of the spinal cord that their study affords valuable indications as to the seat and character of the lesions. They may be divided into—

1. Skin or superficial, and
2. Tendon or deep reflexes.

The skin reflexes, characterized by contraction of underlying muscles, are induced by irritation of the skin—*i. e.*, pricking, pinching, scratching, etc. The following are the principal skin reflexes:

1. *Plantar reflex,* consisting of contraction of the muscles of the foot, induced by stimulation of the sole of the foot; it involves the integrity of the reflex arc through the lower end of the cord.
2. *Gluteal reflex,* consisting of contraction of the glutei muscles when the skin over the buttock is stimulated; it takes place through the segments giving origin to the fourth and fifth lumbar nerves.
3. *Cremasteric reflex,* consisting of a contraction of the cremaster muscle and a retraction of the testicle toward the abdominal ring when the skin on the inner side of the thigh is stimulated; it depends upon the integrity of the segments giving origin to the first and second lumbar nerves.
4. *Abdominal reflex,* consisting of a contraction of the abdominal muscles when the skin upon the side of the abdomen is gently scratched; its production requires the integrity of the spinal segments from the eighth to the twelfth dorsal nerves.
5. *Epigastric reflex,* consisting of a slight muscular contraction in the neighborhood of the epigastrium when the skin between the fourth and sixth ribs is stimulated; it requires the integrity of the cord between the fourth and seventh dorsal nerves.
6. The *scapular reflex* consists of a contraction of the scapular muscles when the skin between the scapulæ is stimulated; it depends upon the integrity of the cord between the fifth cervical and third dorsal nerves.

The superficial reflexes, though variable, are generally present in health. They are increased or exaggerated when the gray matter of the cord is abnormally excited, as in tetanus, strychnia-poisoning, and disease of the lateral columns.

The tendon reflexes, characterized by the contraction of a muscle, are also of much value in the diagnosis of lesions of the spinal cord and are elicited by a sharp blow on a tendon. The following are the principal tendon reflexes:

1. *Patellar reflex,* or *knee-jerk,* consisting of a contraction of the

extensor muscles of the thigh when the ligamentum patellæ is struck between the patella and tibia. This reflex is best observed when the legs are freely hanging over the edge of a table. The patellar reflex is generally present in health, being absent in only two per cent.; it is greatly exaggerated in lateral sclerosis and in descending degeneration of the cord; it is absent in locomotor ataxia and in atrophic lesions of the anterior gray cornua.

2. *Ankle-jerk or Ankle Reflex.*—If the extensor muscles of the leg be placed upon the stretch and the tendo Achillis be sharply struck, a quick extension of the foot will take place.
3. *Ankle-clonus.*—This consists of a series of rhythmic reflex contractions of the gastrocnemius muscle, varying in frequency from six to ten a second. To elicit this reflex, pressure is made upon the sole of the foot so as suddenly and energetically to flex the foot at the ankle, thus putting the tendo Achillis and the gastrocnemius muscle on the stretch. The rhythmic movements thus produced continue so long as the tension, within limits, is maintained. Ankle-clonus is never present in health, but is very marked in lateral sclerosis of the cord.

The *toe reflex, peroneal reflex,* and *wrist reflex* are also present in sclerosis of the lateral columns and in the late rigidity of hemiplegia.

Special Nerve Centers in Spinal Cord.—Throughout the spinal cord there are a number of spinal nerve centers, capable of being excited reflexly and of producing complex coördinated movements. Though for the most part independent in action, they are subject to the controlling influences of the medulla and brain.

1. *Ciliospinal* center, situated in the cord between the lower cervical and the third dorsal vertebra. It is connected with the dilatation of the pupil through fibers which emerge in this region and enter the cervical sympathetic. Stimulation of the cord in this locality causes dilatation of the pupil on the same side; destruction of the cord is followed by contraction of the pupil.
2. *Genitospinal* center, situated in the lower part of the cord. This is a complex center, and comprises a series of subordinate centers for the control of the muscular movements involved in the acts of defecation, micturition, and ejaculation of semen, and of the movements of the uterus during parturition, etc.

3. *Vaso-motor* centers, giving origin to both vaso-constrictor and vaso-dilator fibers, which are distributed throughout the cord. Though acting reflexly, they are under the dominating influence of the center in the medulla.
4. *Sweat*-centers are also present in various parts of the cord.

2. As a Conductor.

The white matter of the spinal cord consists of nerve-fibers, the specific function of which is,

1. To conduct nerve impulses from one segment of the cord to another.
2. To conduct nerve impulses coming from the encephalon to the spinal cord segments.
3 To conduct nerve impulses coming to the cord through afferent nerves, directly or indirectly to the encephalon.

Intersegmental Conduction.—The spinal cord consists of a series of physiologic segments each of which has a special function and is associated through its related spinal nerve with a definite segment of the body. For the harmonious coöperation and coördination of all the spinal segments it is essential that they should be united by commissural or associative fibers. The cord thus becomes capable of complex and purposive reflex actions.

Encephalo-spinal, or Motor Conduction.—The nerve-fibers which conduct volitional impulses from the brain downward to the anterior cornua arise in the motor centers of the cerebrum; they then pass downward through the corona radiata, the internal capsule, the inferior portions of the crura cerebri, the pons Varolii, to the medulla oblongata, where the motor tract of each side divides into two portions, viz.:

1. The *larger*, containing ninety-one to ninety-seven per cent. of the fibers, which decussates at the lower border of the medulla and passes down in the *lateral column* of the opposite side, and constitutes the *crossed pyramidal tract*.
2. The *smaller,* containing three to nine per cent. of the fibers, does not at once decussate, but passes down the *anterior column* of the same side, and constitutes the *direct pyramidal tract,* or the column of Türck. At a lower level this tract also decussates or crosses over to the opposite side of the cord.

The fibers of both the crossed and the direct pyramidal tracts come into relation by their terminal branches with the nerve-cells in the

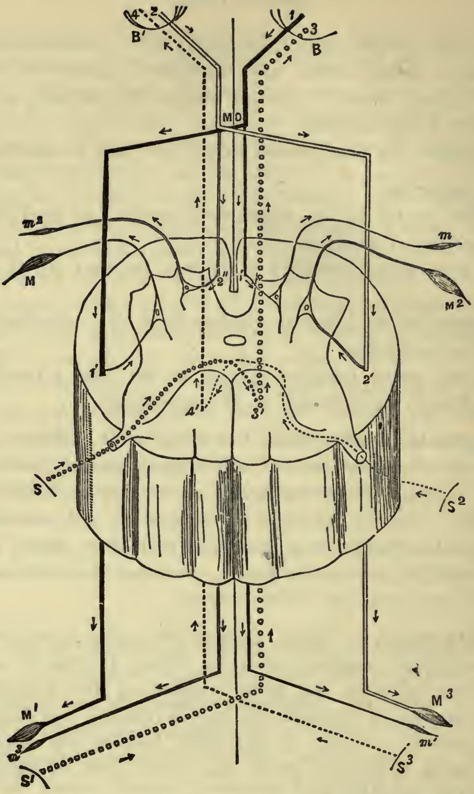


FIG. 22.—DIAGRAM SHOWING THE COURSE, THROUGH THE SPINAL CORD, OF THE MOTOR AND SENSORY NERVE-FIBERS.

B and B′ represent the right and left hemispheres of the brain, from which the motor fibers take their origin, and in which the sensory fibers terminate. The *motor tract* from the right side, 1, passes down through the crus, through the pons to the medulla oblongata, where it divides into two portions: (1) The *larger portion,* ninety-seven per cent., crosses over to the opposite side of the cord and passes down through the lateral column. It gives off fibers at different levels, which pass into the gray matter and become connected with the muscles, M, through the multipolar cells. (2) The *smaller portion,* three per cent., does not cross over, but descends on the same side of the cord in the anterior column and supplies the muscles, *m.* The same is true for the motor tract for the left hemisphere.

The *sensory fibers* from the left side of the body enter the gray matter through the posterior roots. They then cross over at once to the opposite side of the cord and ascend to the hemisphere, partly in the gray matter, partly in the posterior column. The same is true for the sensory nerves of the right side of the body.

anterior cornu of the gray matter of the opposite side of the cord. (Fig. 22.)

Through this decussation each half of the cerebrum governs the muscle movements of the opposite side of the body.

The fibers composing the crossed and the direct pyramidal tracts are therefore the channels by which the volitional nerve impulses are conducted from the motor area of the cortex to the multipolar cells in the anterior cornua of the gray matter of the spinal cord, and by them and their related nerves transmitted to the muscles.

Spino-encephalic, or Sensor Conduction.—The nerve impulses that are brought to the spinal cord by the afferent spinal nerve-fibers are transmitted by afferent paths in the cord for the most part to the cortex of the cerebrum where they are translated into conscious sensations. These paths are therefore termed sensor. The sensor tract passes through the cord, the medulla oblongata, the pons Varolii, the superior portion of the crus cerebri, the posterior third of the posterior limb of the internal capsule, to sensor perceptive areas in the cerebral cortex. The sensor pathway decussates at all levels of the spinal cord and medulla, and therefore the sensibility of each side of the body is associated with the opposite side of the brain.

The paths for the nerve impulses that give rise to different sensations have been variously located by different observers. The pathway for the impulses that give rise to the sensations of temperature has been located in the gray matter; the pathway for the impulses that give rise to the sensation of pain has been located in Gower's tract; the pathway for tactile impressions has been located in the posterior columns.

Properties of the Spinal Cord.—Irritation applied directly to the *anterolateral* white columns produces muscular movements, but no pain; they are, therefore, *excitable,* but *insensible.*

The surface of the *posterior* columns is not sensitive to direct irritation, except near the origin of the posterior roots. The sensibility is due, however, *not* to its own proper fibers, but to the fibers of the posterior root, which traverse it.

Division of the *anterolateral* columns abolishes all power of voluntary movement in the lower extremities.

Division of the *posterior* column impairs the power of muscular coördination, such as is witnessed in locomotor ataxia.

The *gray matter* is probably both *insensible* and *inexcitable* under the influence of direct stimulation.

A *transverse section* of one lateral half of the cord produces—

1. On the *same* side, paralysis of voluntary motion, a relative or absolute elevation of temperature, and an increased flow of blood in the paralyzed parts; hyperesthesia, for the sense of contact, tickling, pain, and temperature.
2. On the *opposite* side, complete anesthesia as regards contact, tickling, and temperature in the parts corresponding to those which are paralyzed in the opposite side, with a complete preservation of voluntary power and of the muscular sense.

A *vertical* section through the middle of the *gray matter* results in the loss of sensation on both sides of the body below the section, but no loss of voluntary power.

Paralysis from Injuries of the Spinal Cord.

Seat of Lesion.—If it be in the *lower part* of the *sacral canal,* there is paralysis of the compressor urethræ, accelerator urinæ, and sphincter ani muscles; no paralysis of the muscles of the leg.

At the Upper Limit of the Sacral Region.—Paralysis of the muscles of the bladder, rectum and anus; loss of sensation and motion in the muscles of the legs, except those supplied by the anterior crural and obturator—viz., psoas iliacus, sartorius, pectineus, adductor longus, magnus, and brevis, obturator, vastus externus and internus, etc.

At the Upper Limit of the Lumbar Region.—Sensation and motion paralyzed in both legs; loss of power over the rectum and bladder; paralysis of the muscular walls of the abdomen, interfering with expiratory movements.

At the Lower Portion of the Cervical Region.—Paralysis of the legs, etc., as in the foregoing; in addition, paralysis of all the intercostal muscles and consequent interference with respiratory movements; paralysis of muscles of the upper extremities, except those of the shoulders.

Above the Middle of the Cervical Region.—In addition to the preceding, difficulty of deglutition and vocalization, contraction of the pupils, paralysis of the diaphragm, scalene muscles, intercostals, and many of the accessory respiratory muscles; death resulting immediately from arrest of respiratory movements.

THE MEDULLA OBLONGATA.

The medulla oblongata is the expanded portion of the upper part of the spinal cord. It is pyramidal in form and measures 1½ inches in length, ¾ of an inch in breadth, ½ of an inch in thickness, and is divided into two lateral halves by the anterior and posterior median fissures, which are continuous with those of the cord. Each half is again subdivided by minor grooves into four columns—viz., *anterior, pyramid, lateral* and *tract olivary body, restiform body,* and *posterior pyramid.*

1. The *anterior pyramid* is composed partly of fibers continuous with those of the anterior column of the spinal cord, but mainly of fibers derived from the lateral tract of the opposite side by *decussation.* The united fibers then pass upward through the pons

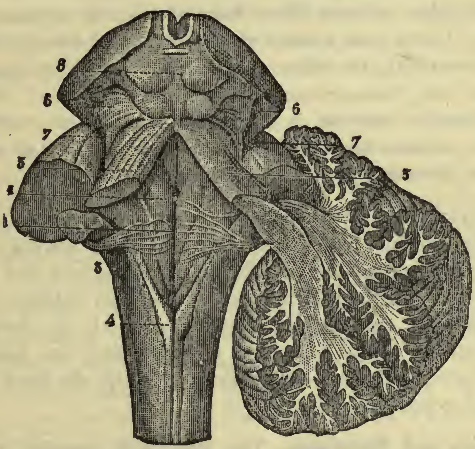


Fig. 23.—View of Cerebellum in Section, and of Fourth Ventricle, with the Neighboring Parts.—(*From Sappey.*)

1. Median groove fourth ventricle, ending below in the *calamus scriptorius,* with the longitudinal eminences formed by the fasciculi teretes, one on each side. 2. The same groove, at the place where the white streaks of the auditory nerve emerge from it to cross the floor of the ventricle. 3. Inferior peduncle of the cerebellum, formed by the restiform body. 4. Posterior pyramid; above this is the calamus scriptorius. 5, 5. Superior peduncle of cerebellum, or *processus e cerebello ad testes.* 6, 6. Fillet to the side of the crura cerebri. 7, 7. Lateral grooves of the crura cerebri. 8. *Corpora quadrigemina.* (*After Hirschfeld and Leveille.*)

Varolii and crura cerebri, and for the most part terminate in the corpus striatum and cerebrum.

2. The *lateral tract* is continuous with the lateral columns of the cord; its fibers in passing upward take three directions—viz., an external bundle joins the restiform body, and passes into the cerebellum; an internal bundle decussates at the median line and joins the opposite anterior pyramid; a middle bundle ascends beneath the olivary body, behind the pons, to the cerebrum, as the *fasciculus teres.* The *olivary body* of each side is an oval mass, situated between the anterior pyramid and restiform body; it is composed of white matter externally and gray matter internally, forming the *corpus dentatum.*
3. The *restiform body,* continuous with the posterior column of the cord, also receives fibers from the lateral column. As the restiform bodies pass upward they diverge and form a space (the fourth ventricle), the floor of which is formed by gray matter, and then turn backward and enter the cerebellum.
4. The *posterior pyramid* is a narrow white cord bordering the posterior median fissure; it is continued upward, in connection with the *fasciculus teres,* to the cerebrum.

The **gray matter** of the medulla is continuous with that of the cord. It is arranged with much less regularity, becoming blended with the white matter of the different columns, with the exception of the anterior. By the separation of the posterior columns the transverse commissure is exposed, forming part of the floor of the fourth ventricle; special collections of gray matter are found in the posterior portions of the medulla, connected with the roots of origin of different cranial nerves.

Properties and Functions.—The medulla is excitable anteriorly, and sensitive posteriorly, to direct irritation. It serves—

1. As a conductor of afferent or sensor impulses upward from the cord, through the gray matter to the cerebrum.
2. As a conductor of efferent, volitional or motor impulses from the brain to the spinal cord and nerves, through its anterior pyramids.
3. As a conductor of coördinating impulses from the spinal cord to the cerebellum, through the restiform bodies.

As an Independent Reflex Center.—The medulla oblongata contains special collections of gray matter, constituting independent nerve centers presiding over different functions, some of which are as follows—viz.:

1. A center which controls the movements of *mastication,* through afferent and efferent nerves.
2. A center reflecting impressions which influence the *secretion* of *saliva.*
3. A *center for sucking, mastication, and deglutition,* whence are derived motor stimuli exciting to action and coördinating the muscles of the palate, pharynx, and esophagus, necessary for the swallowing of the food.
4. A center which coördinates the muscles concerned in the act of *vomiting.*
5. A *speech center,* coördinating the various muscles necessary for the accomplishment of articulation through the hypoglossal, facial nerves, and the second division of the fifth pair.
6. A center for the harmonization of muscles concerned in *expression,* reflecting its impulses through the facial nerve.
7. A *cardiac center,* which exerts (1) an *accelerating* influence over the heart's pulsations through accelerating nerve-fibers emerging from the cervical portion of the cord, entering the inferior cervical ganglion, and thence passing to the heart; (2) an *inhibitory* or retarding influence upon the action of the heart, through fibers of the spinal accessory nerve running in the trunk of the pneumogastric. The cardio-inhibitory center is in a state of tonic activity and continuously sends impulses to the heart which exert an inhibitory influence upon its action. It may be stimulated directly by anemia as well as by venous hyperemia of the blood-vessels of the medulla and increased venosity of the blood. It is excited reflexly by the stimulation of the central end of the vagus, sciatic, and splanchnic nerves.
8. A *vaso-motor center,* which, by alternately contracting and dilating the blood-vessels through nerves distributed in their walls, regulates the quantity of blood distributed to an organ or tissue, and thus influences nutrition, secretion, and calorification. The vaso-motor center is situated in the medulla oblongata and pons Varolii, between the *corpora quadrigemina* and the *calamus scriptorius.* The vaso-motor fibers having their origin in this center descend through the interior of the cord, emerge through the anterior roots of spinal nerves, enter the ganglia of the sympathetic, and thence pass to the walls of the blood-vessels, and maintain an

arterial tonus; they may be divided into two classes—viz., *vaso-dilators* (*e. g.,* chorda tympani) and *vaso-constrictors* (*e. g.,* sympathetic fibers).

Division of the cord at the lower border of the medulla is followed by a dilatation of the entire vascular system and a marked fall of the blood pressure. *Electric stimulation* of the distal surface of the cord is followed by a contraction of the blood-vessels and a rise in the blood pressure.

The vaso-motor center is stimulated directly by the condition of the blood in the medulla oblongata. When the blood is highly venous this center becomes very active, the blood-vessels throughout the body are contracted, and the blood current becomes swifter; sudden anemia of the medulla has a similar effect. The action of the vaso-motor center may be accelerated, with attendant rise of blood pressure, by irritation of certain afferent nerve-fibers. These are known as *pressor* fibers. On the other hand, its action may be depressed by other fibers, with attendant fall of blood pressure. These are known as *depressor* fibers.

9. A *diabetic center,* irritation of which causes an increase in the amount of urine secreted and the appearance of a considerable quantity of sugar in the urine.
10. *Respiratory center,* situated near the origin of the pneumogastric nerves, presides over the movements of respiration and its modifications, laughing, singing, sobbing, sneezing, etc. It may be excited *reflexly* by the presence of carbonic acid in the lungs irritating the terminal pneumogastric filaments; or *automatically,* according to the character of the blood circulating through it; an *excess* of carbonic acid or a diminution of oxygen increasing the number of respiratory movements; a reverse condition diminishing the respiratory movements.
11. A *spasm center,* stimulation of which gives rise to convulsive phenomena, such as coughing, sneezing, etc.
12. A *center for certain ocular functions,* governing the closure of the eyelids and dilatation of the pupil.
13. A *sweat center* is also localized in the medulla.

THE PONS VAROLII.

The **pons Varolii** is united with the cerebrum above, the cerebellum behind, and the medulla oblongata below. It consists of transverse and longitudinal fibers, amidst which are irregularly scattered collections of gray or vesicular nervous matter.

The *transverse fibers* unite the two lateral halves of the cerebellum.

The *longitudinal fibers* are continuous—

1. With the anterior pyramids of the medulla oblongata, which, interlacing with the deep layers of the transverse fibers, ascend to the crura cerebri, forming their superficial or fasciculated portions.
2. With fibers derived from the olivary fasciculus, some of which pass to the tubercula quadrigemina, while others, uniting with fibers from the lateral and posterior columns of the medulla, ascend in the deep or posterior portions of the crura cerebri.

Properties and Functions.—The superficial portion is *insensible* and *inexcitable* to direct irritation; the deeper portion appears to be *excitable,* consisting of descending motor fibers; the posterior portions are *sensible,* but *inexcitable* to irritation.

Transmits motor and sensor impulses from and to the cerebrum.

The *gray ganglionic* matter consists of centers which convert impressions into more or less conscious sensations and originate motor impulses, these taking place independent of any intellectual process; they are the seat of instinctive reflex acts, the centers which assist in the coördination of the automatic movements of station and progression.

THE CRURA CEREBRI.

The **crura cerebri** are largely composed of the longitudinal fibers of the pons (anterior pyramids, fasciculi teretes); after emerging from the pons they increase in size, and become separated into two portions by a layer of dark-gray matter, the *locus niger.*

The *superficial* portion, the *crusta,* composed of the anterior pyramids, constitutes the *motor tract,* which terminates, for the most part, in the *corpus striatum,* but to some extent, also, in the cerebrum; the *deep portion,* made up of the fasciculi teretes and posterior pyramids and accessory fibers from the cerebellum, constitutes the *sensor tract* (the *tegmentum*), which terminates in the *optic thalamus* and cerebrum.

Function.—The crura are conductors of motor and sensor impulses; the gray matter assists in the coördination of the complicated movements of the eyeball and iris, through the motor oculi communis nerve. It also assists in the harmonization of the general muscular movements, as section of one crus gives rise to peculiar movements of rotation and somersaults forward and backward.

THE CORPORA QUADRIGEMINA.

The **corpora quadigemina** are four small, rounded eminences, two on each side of the median line, situated immediately behind the third ventricle, and beneath the posterior border of the corpus callosum.

The *anterior* tubercles are oblong from before backward, and larger than the *posterior,* which are hemispheric in shape; they are grayish in color, but consist of white matter externally and gray matter internally.

Both the anterior and posterior tubercles are connected with the optic thalami by commissural bands, named the *anterior* and *posterior brachia,* respectively. They receive fibers from the olivary fasciculus and fibers from the cerebellum, which press upward to enter the optic thalami.

The *corpora geniculata* are situated, one on the inner side and one on the outer side of each optic tract, behind and beneath the optic thalamus, and from their position are named the *corpora geniculata interna* and *externa;* they give origin to fibers of the optic nerve.

Functions.—The *corpora quadrigemina* are centers associated with the visual centers. Destruction of these tubercles is immediately followed by a loss of the sense of sight; moreover, their action in vision is crossed, owing to the decussation of the optic tracts, so that if the tubercle of the right side be destroyed by disease or extirpated, the sight is *lost* in the eye of the opposite side, and the iris loses its mobility.

The tubercula quadrigemina as nerve centers preside over the reflex movements which cause a dilatation or contraction of the iris, irritation of the tubercles causing contraction, destruction causing dilatation. Removal of the tubercles on one side produces a temporary loss of power of the opposite side of the body, and a tendency to move around an axis is manifested, as after a section of one crus cerebri, which, however, may be due to giddiness and loss of sight.

They also assist in the coördination of the complex movements of the eye, and regulate the changes of the iris during the movements of accommodation.

CORPORA STRIATA AND OPTIC THALAMI.

The **corpora striata** are two large ovoid collections of gray matter, situated at the base of the cerebrum, the larger portions of which are embedded in the white matter, the smaller portions projecting into the anterior part of the lateral ventricle. Each striated body is divided, by a narrow band of white matter, into two portions—viz.:

1. The *caudate nucleus,* the intraventricular portion, which is conic in shape, having its apex directed backward, as a narrow, tail-like process.
2. The *lenticular nucleus,* embedded in the white matter, and for the most part external to the ventricle. On the outer side of the lenticular nucleus is found a narrow band of white matter, the *external capsule;* and between it and the convolutions of the island of Reil, a thin band of gray matter, the *claustrum.*

The corpora striata are grayish in color, and when divided, present transverse striations, from the intermingling of white fibers and gray cells.

The **optic thalami** are two oblong masses situated in the ventricles posterior to the corpora striata, and resting upon the posterior portion of the crura cerebri. The internal surface, projecting into the lateral ventricles, is white, but the interior is grayish, from a commingling of both white fibers and gray cells. Separating the lenticular nucleus from the caudate nucleus and the optic thalamus is a band of white tissue, the *internal capsule.*

The *internal capsule* is a narrow, curved tract of white matter, and is, for the most part, an expansion of the *motor tract* of the crura cerebri. It consists of two segments—an *anterior,* situated between the caudate nucleus and the anterior surface of the lenticular nucleus, and a *posterior,* situated between the optic thalamus and the posterior surface of the lenticular nucleus. These two segments unite at an obtuse angle, which is directed toward the median line. Pathologic observation has shown that the nerve-fibers of the direct and crossed pyramidal tracts can be traced upward through the anterior two thirds of the posterior segment into the centrum ovale, where, for the most part, they are lost; a portion, however, remaining united, ascend higher and terminate in the paracentral lobule, and in the ascending frontal convolution. Those of the *sensor tract* can be traced upward, through the posterior third, into the cerebrum, where they probably terminate in the ascending parietal and the superior parietal convolutions and in the gyrus fornicatus.

Functions.—The *corpora striata* are the centers in which terminate some of the fibers of the superficial or *motor* tract of the crura cerebri; others pass upward through the *internal capsule,* to be distributed to the cerebrum. It might be inferred, from their anatomic relations, that the corpora striata are motor centers. *Irritation* by a weak galvanic current produces muscular movements of the opposite side of the body; *destruction* of their substance by a hemorrhage, as in apoplexy, is followed by a paralysis of motion of the opposite side of the body, but there is no loss of sensation. When the hemorrhagic destruction involves the fibers of the anterior two thirds of the posterior segment of the internal capsule, and thus separates them from their trophic centers in the cortical motor region, a descending degeneration is established, which involves the direct pyramidal tract of the same side and the crossed pyramidal tract of the opposite side.

Destruction of the posterior one third of the posterior segment of the internal capsule is followed by a loss of sensation on the opposite side of the body and a loss of the senses of smell and vision on the same side (Charcot). The precise function of the corpora striata is unknown, but they are in some way connected with motion.

The *optic thalami* receive the fibers of the *tegmentus,* the posterior portion of the crura cerebri. They are insensible and inexcitable to direct irritation. Removal of one optic thalamus, or destruction of its substance by disease or hemorrhage, is followed by a loss of sensibility of the opposite side of the body, but there is no loss of motion; their precise function is also unknown, but they are in some way connected with *sensation.* In both cases their action is crossed.

THE CEREBELLUM.

The cerebellum is situated in the inferior fossæ of the occipital bone, beneath the posterior lobes of the cerebrum. It attains its maximum weight, which is about five ounces, between the twenty-fifth and fortieth years, the proportion between the cerebellum and cerebrum being as 1 to $8\frac{4}{7}$.

It is composed of *two lateral hemispheres* and a central elongated lobe, the *vermiform process;* the two hemispheres are connected with each other by the fibers of the *middle peduncle,* forming the superficial portion of the pons Varolii. The cerebellum is brought into connection with the *medulla oblongata* and *spinal cord* through the prolongation of the *restiform* bodies; with the cerebrum, by fibers passing upward beneath the corpora quadrigemina and the optic thalami, and then forming part of the diverging cerebral fibers.

Structure.—It is composed of both white and gray matter, the former being internal, the latter external, and is convoluted, for economy of space.

The *white matter* consists of a central stem, the interior of which is a dentated capsule of gray matter, the *corpus dentatum.* From the external surface of the stem of white matter processes are given off, forming the *laminæ,* which are covered with gray matter.

The *gray matter* is convoluted and covers externally the laminated processes; a vertical section through the gray matter reveals the following structures:

1. A delicate *connective-tissue layer,* just beneath the pia mater, containing rounded corpuscles, and with branching fibers passing toward the external surface.
2. *The cells of Purkinje,* forming a layer of large, nucleated, branched nerve-cells sending off processes to the external layer.
3. *A granular layer* of small but numerous corpuscles.
4. *A nerve-fiber layer,* formed by a portion of the white matter.

Properties and Functions.—Irritation of the cerebellum is not followed by any evidences either of pain or convulsive movements; it is, therefore, *insensible* and *inexcitable.*

Coördination of Movements.—Removal of the superficial portions of the cerebellum in pigeons produces *feebleness* and *want of harmony* in the muscular movements; as successive slices are removed, the movements become more irregular, and the pigeon becomes restless; when the last portions are removed, all power of *flying, walking, standing,* etc., is entirely gone, and the *equilibrium* can not be maintained, the power of *coördinating* muscular movements being wholly lost. The same results have been obtained by operating on all classes of animals.

The following symptoms were noticed by Wagner, after removing the whole or a large part of the cerebellum:

1. A tendency on the part of the animal to throw itself on one side, and to extend the legs as far as possible.
2. Torsion of the head on the neck.
3. Trembling of the muscles of the body, which was general.
4. Vomiting and occasional liquid evacuations.

Forced Movements.—Division of *one crus cerebelli* causes the animal to fall on one side and roll rapidly on its longitudinal axis. According to Schiff, if the peduncle be divided from *behind,* the animal falls on the same side as the injury; if the section be made in *front,* the animal turns to the opposite side.

Disease of the cerebellum partially corroborates the result of experiments; in many cases symptoms of unsteadiness of gait, from a *want of coördination,* have been noticed.

Comparative anatomy reveals a remarkable correspondence between the development of the cerebellum and the increase in complexity of muscular actions. It attains a much greater development, relatively to the rest of the brain, in those animals whose movements are very complex and varied in character, such as the kangaroo, shark, and swallow.

The cerebellum may possibly exert some influence over the sexual functions, but physiologic and pathologic facts are opposed to the idea of its being the seat of the sexual instinct. It appears to be simply a center for the coördination and equilibration of muscular movements.

THE CEREBRUM.

The **cerebrum** is the largest portion of the encephalic mass, constituting about four fifths of its weight; the average weight of the adult male brain is from forty-eight to fifty ounces, or about three pounds while that of the adult female is about five ounces less.

After the age of forty the weight of the cerebrum gradually diminishes at the rate of one ounce every ten years. In idiots the brain weight is often below the normal, at times not amounting to more than twenty ounces.

The cerebrum is connected with the pons Varolii and medulla oblongata through the crura cerebri, and with the cerebellum through the superior peduncles. It is divided into two lateral halves, or hemispheres, by the longitudinal fissure running from before backward in the median line; each hemisphere is composed of both *white* and *gray* matter, the former being internal, the latter external; it covers the surfaces of the hemisphere which are infolded, forming fissures and convolutions.

Fissures.

1. The *fissure of Sylvius* is one of the most important; it is the first to appear in the development of the fetal brain, being visible at about the third month; in the adult it is quite deep and well marked, running from the under surface of the brain upward, outward, and backward, and forms a boundary between the frontal and temporosphenoid lobes.
2. The *fissure of Rolando* is second in importance, and runs from a point on the convexity near the median line transversely outward and downward toward the fissure of Sylvius, but does not enter it. It separates the frontal from the parietal lobe.
3. The *parietal fissure,* arising a short distance behind the fissure of Rolando, upon the convexity of the hemisphere, runs downward and backward to its posterior extremity.
4. The *parieto-occipital fissure* separates the occipital from the parietal lobe. Beginning upon the outer surface of the cerebrum, it is continued on the mesial aspect downward and forward until it terminates in the calcarine fissure.
5. The *callosomarginal fissure* lies upon the mesial surface, where it runs parallel with the corpus callosum.

Secondary fissures of importance are found in different lobes of the cerebrum, separating the various convolutions. In the anterior lobe are found the *precentral, superior frontal,* and *inferior frontal* fissures; in the temporosphenoid lobes are found the *first* and *second temporosphenoid fissure;* in the occipital lobe, the *calcarine* and *hippocampal fissures.*

Convolutions. Frontal Lobe.

The *ascending frontal* or *precentral convolution,* situated in front of the fissure of Rolando runs downward and forward; it is con-

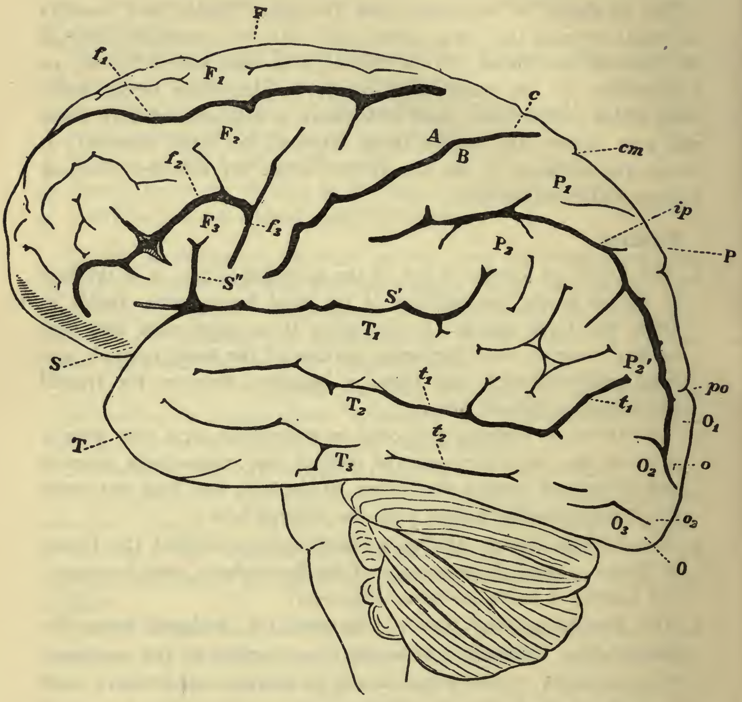


FIG. 24.—DIAGRAM SHOWING FISSURES AND CONVOLUTIONS OF THE LEFT SIDE OF THE HUMAN BRAIN.—(*Landois' "Physiology."*)

F. Frontal. P. Parietal. O. Occipital. T. Temporosphenoid lobe. S. Fissure of Sylvius. S′. Horizontal. S″. Ascending ramus of S. c. Sulcus centralis, or fissure of Rolando. A. Ascending frontal, and B. Ascending parietal convolutions. F_1. Superior, F_2. Middle, and F_3. Inferior frontal convolutions. f_2. Superior, f_2. Inferior frontal fissures. f_3. Sulcus præcentralis. P_1. Superior parietal lobule. P_2. Inferior parietal lobule, consisting of P_2. Supramarginal gyrus, and P_2'. Angular gyrus. *ip*. Sulcus interparietalis. *cm*. Termination of callosomarginal fissure. O_1. First, O_2. Second, O_3. Third occipital convolutions. *po*. Parieto-occipital fissure. *o*. Transverse occipital fissure. o_2. Inferior longitudinal occipital fissure. T_1. First, T_2. Second, T_3. Temporosphenoid, convolutions. t_1, t_2. First, t_2. Second, temporosphenoid fissures.

tinuous above with the anterior frontal, and below with the inferior frontal, convolution.

The *superior frontal convolution* is bounded internally by the longitudinal fissure, and externally by the superior frontal fissure; it is connected with the superior end of the frontal convolution, and runs downward and forward to the anterior extremity of the frontal lobe, where it turns backward, and rests upon the orbital plate of the frontal bone.

The *middle frontal convolution,* the largest of the three, runs from behind forward, along the sides of the lobe, to its anterior part; it is bounded above by the superior and below by the inferior frontal fissures.

The *inferior frontal convolution* winds around the ascending branch of the fissure of Sylvius, in the anterior and inferior portion of the cerebrum.

Parietal Lobe.—The *ascending parietal convolution* is situated just behind the fissure of Rolando, running downward and forward; above, it becomes continuous with the upper parietal convolution, and below, winds around to be united with the ascending frontal.

The *upper parietal convolution* is situated between the parietal and longitudinal fissures.

The *supramarginal convolution* winds around the superior extremity of the fissure of Sylvius.

The *angular convolution,* a continuation of the preceding, follows the parietal fissure to its posterior extremity, and then makes a sharp angle downward and forward.

Temporosphenoid Lobe.—Contains three well-marked convolutions, the *superior, middle* and *inferior,* separated by well-defined fissures, and continuous posteriorly with the convolutions of the parietal lobe.

The **occipital lobe** lies behind the parieto-occipital fissure, and contains the *superior, middle* and *inferior* convolutions, not well marked.

The *central lobe,* or *island of Reil,* situated at the bifurcation of the fissure of Sylvius, is a triangular-shaped cluster of six convolutions, the *gyri operti,* which are connected with those of the frontal, parietal, and temporosphenoid lobes.

Upon the *inner* or *mesial* aspect of the hemisphere are found (Fig. 25)—

1. The *paracentral lobule,* lying in the region of the upper extremity of the fissure of Rolando; it contains the large giant cells of Betz. Injury to this convolution is followed by degeneration of the motor tract.
2. The *gyrus fornicatus,* lying below the callosomarginal fissure. Running parallel with the corpus callosum, it terminates at its posterior border in the hippocampal gyrus.

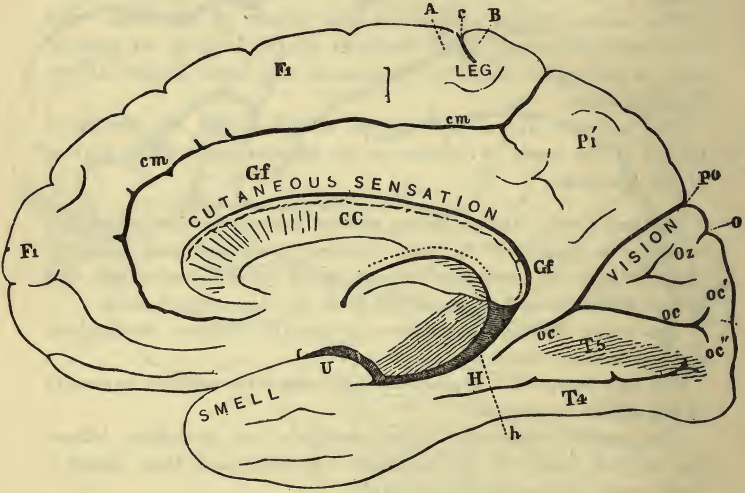


Fig. 25.—Diagram showing Fissures and Convolutions on Mesial Aspect of the Right Hemisphere.

Median aspect of the right hemisphere. CC. Corpus callosum divided longitudinally. Gf. Gyrus fornicatus. H. Gyrus hippocampi. *h.* Sulcus hippocampi. U. Uncinate gyrus. *cm.* Callosomarginal fissure. F$_1$. First frontal convolution. *c.* Terminal portion of fissure of Rolando. A. Ascending frontal, B. Ascending parietal, convolution and paracentral lobule. P$_1'$. Præcuneus or quadrate lobule. Oz. Cuneus. Po. Parieto-occipital fissure. *o.* Transverse occipital fissure. *oc.* Calcarine fissure. oc'. Superior, oc''. Inferior, rami of the same. D. Gyrus descendens. T$_4$. Gyrus occipitotemporalis lateralis (lobulus fusiformis). T$_5$. Gyrus occipitotemporalis medialis (lobulus lingualis).

3. The *gyrus hippocampus* (H) is formed by the union of the preceding convolution with the occipitotemporal. It runs forward and terminates in a hooked extremity—*uncus.*
4. The *quadrate lobule,* or *præcuneus,* lies between the upper extremity of the callosomarginal fissure and the parieto-occipital.

5. The *cuneus* lies posteriorly to the quadrate lobule. It is a wedge-shaped mass inclosed by the calcarine and parieto-occipital fissures.

Structure.—The *gray matter* of the cerebrum, about ⅛ of an inch thick, is composed of five layers of nerve-cells:

1. A superficial layer, containing a few small multipolar ganglion cells.
2. Small ganglion cells, pyramidal in shape.
3. A layer of large pyramidal ganglion cells with processes running off superiorly and laterally.
4. The granular formation containing nerve-cells.
5. Spindle-shaped and branching nerve-cells of a moderate size.

The *white matter* consists of three distinct sets of fibers.

1. The *diverging* or *peduncular* fibers are mainly derived from the columns of the cord and medulla oblongata; passing upward through the crura cerebri they receive accessory fibers from the olivary fasciculus, corpora quadrigemina, and cerebellum. Some of the fibers terminate in the optic thalami and corpora striata, while others radiate into the anterior, middle, and posterior lobes of the cerebrum.
2. The *transverse commissural* fibers connect the two hemispheres, through the corpus callosum and anterior and posterior commissures.
3. The *longitudinal commissural* fibers connect different parts of the same hemisphere.

Functions.—The cerebral hemispheres are the centers of the nervous system through which are manifested all the phenomena of the mind; they are the centers in which impressions are registered and reproduced subsequently as ideas; they are the seat of intelligence, reason, and will.

However important a center the cerebrum may be for the exhibition of this highest form of nervous action, it is not directly essential for the continuance of life, for it does not exert any control over those automatic reflex acts, such as respiration, circulation, etc., which regulate the functions of organic life.

From the study of comparative anatomy, pathology, vivisection, etc., evidence has been obtained which throws some light upon the physiology of the cerebral hemispheres.

1. *Comparative anatomy* shows that there is a general connection between the size of the brain, its texture, the depth and number

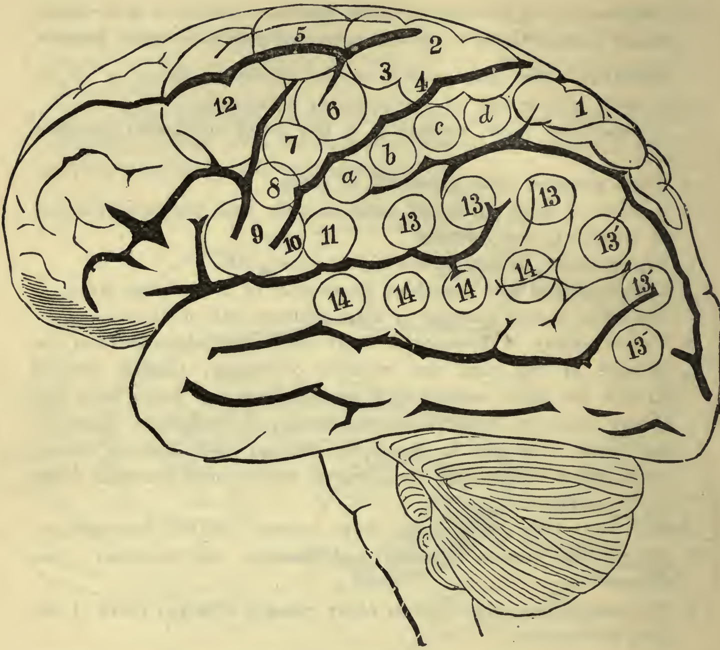


Fig. 26.—Side View of the Brain of Man, with the Areas of the Cerebral Convolutions according to Ferrier.

The figures are constructed by marking on the brain of man, in their respective situations, the areas of the brain of the monkey as determined by experiment, and the description of the effects of stimulating the various areas refers to the brain of the monkey.

1. Advance of the opposite hind limb, as in walking. 2, 3, 4. Complex movements of the opposite leg and arm, and of the trunk, as in swimming. *a, b, c, d.* Individual and combined movements of the fingers and wrists of the opposite hand. Prehensile movements. 5. Extension forward of the opposite arm and hand. 6. Supination and flexion of the opposite forearm. 7. Retraction and elevation of the opposite angle of the mouth, by means of the zygomatic muscles. 8. Elevation of the alæ nasi and upper lip, with depression of the lower lip on the opposite side. 9, 10. Opening of the mouth, with (9) protrusion and (10) retraction of the tongue; region of aphasia, bilateral action. 11. Retraction of the opposite angle of the mouth, the head turned slightly to one side. 12. The eyes open widely, the pupils dilate, and the head and eyes turn toward the opposite side. 13, 13′. The eyes move toward the opposite side with an upward (13) or downward (13′) deviation. The pupils are generally contracted. 14. Pricking of the opposite ear, the head and eyes turn to the opposite side, and the pupils dilate widely.

of convolutions, and the exhibition of mental power. Throughout the entire animal series, the increase in intelligence goes hand in hand with an increase in the development of the brain. In man there is an enormous increase in size over that of the highest animals, the anthropoids. The most cultivated races of men have the greatest cranial capacity; that of the educated European being about 116 cubic inches, that of the Australian being about 60 cubic inches, a difference of 56 cubic inches. Men distinguished for great mental power usually have large and well-developed brains; that of Cuvier weighed 64 ounces; that of Abercrombie, 63 ounces; the average being about 48 to 50 ounces. Not only the size, but, above all, the texture, of the brain must be taken into consideration.

2. *Pathology.*—Any severe injury or disease disorganizing the hemispheres is at once attended by a disturbance or an entire suspension of mental activity. A blow on the head, producing concussion, or undue pressure from cerebral hemorrhage, destroys consciousness; physical and chemic alterations in the gray matter have been shown to coexist with insanity, and with loss of memory, speech, etc. Congenital defects of organization from imperfect development are usually accompanied by a corresponding deficiency of intellectual power and of the higher instincts. Under these circumstances no great advance in mental development can be possible, and the intelligence remains of a low grade. In congenital idiocy not only is the brain of small size, but it is wanting in proper chemic composition, *phosphorus,* a characteristic ingredient of the nervous tissue, being largely diminished in amount.

3. *Experimentation* upon the lower animals—*e. g.,* the removal of the cerebral hemispheres, is attended by results similar to those observed in disease and injury. Removal of the cerebrum in pigeons produces complete abolition of intelligence, and destroys the capability of performing spontaneous movements. The pigeon remains in a condition of profound stupor, which is not accompanied, however, by a loss of sensation or of the power of producing reflex or instinctive movements. The pigeon can be temporarily aroused by pinching the feet, loud noises, lights placed before the eyes, etc., but soon relapses into a state of quietude, being unable to remember impressions and connect them with any train of ideas, the faculties of memory, reason, and judgment being completely abolished.

CEREBRAL LOCALIZATION OF FUNCTIONS.

From experiments made upon animals, and from the results of clinical and post-mortem observations upon men, it has been shown that the phenomena of organic and psychic life are presided over by anatomically localized centers in the brain. A knowledge of the position of these centers becomes of the highest importance in localizing the seat of lesions, thrombi, hemorrhages, new growths, etc., which show themselves in paralyses, epilepsies, etc. It has not been possible to thus localize all functions, and to many parts of the brain no special use can be assigned. The following are the centers most definitely mapped out and that are of paramount importance.

Motor Centers.—These are in the cortical gray matter, and are arranged along either side of the fissure of Rolando. This area is known as the *motor area* or *motor zone,* stimulation of which is followed by convulsive movements of the muscles of the opposite side of the body, while destruction of the gray matter of this area is followed by permanent paralysis of the muscles of the opposite side. From experiments made upon monkeys, Ferrier has mapped out a number of motor centers which he has transformed to corresponding localities on the human brain. (See Fig. 26.) The descriptive text of the illustration renders his results intelligible. Pathologic studies have largely confirmed his deductions. In a general way it may be said that the upper third of the ascending frontal and parietal convolutions about this fissure preside over the movements of the leg of the opposite side of the body; the middle third controls the movements of the arm; the upper part of the inferior third is the facial area. The lowest part of the inferior third governs the motility of the lips and tongue, and this space, with the posterior extremity of the third frontal convolution, constitutes the *speech center.*

The experiments of Horsley and Schäfer have enabled them to furnish a new diagrammatic representation of the motor area and more accurately to define the special areas upon the lateral and mesial aspects of the brain of the monkey. The boundaries of the general and special areas, as determined by these observers, will be readily understood by an examination of Figures 27 and 28.

For diagnostic purposes the motor areas for the face and limbs have been subdivided as follows:

1. The *face area* may be divided into an upper part, comprising about one third, and a lower part, comprising the remaining two thirds.

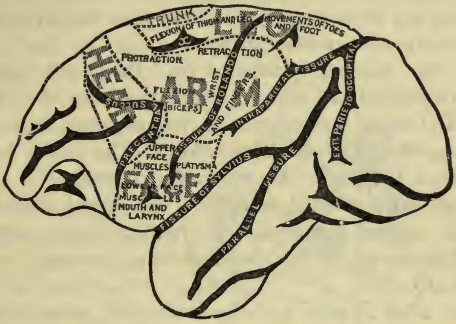

TRUNK
LEG
FLEXION OF THIGH AND LEG
MOVEMENTS OF TOES AND FOOT
HEAD
PROTRACTION
RETRACTION
ARM
FLEXION
(BICEPS)
WRIST AND FINGERS
SULCUS
PRECENTRAL
FISSURE OF ROLANDO
INTRAPARIETAL FISSURE
EXT. PARIETO-OCCIPITAL
UPPER FACE MUSCLES
PLATYSMA
FACE
LOWER FACE MUSCLES
MOUTH AND LARYNX
FISSURE OF SYLVIUS
PARALLEL FISSURE

FIG. 27.—DIAGRAM OF THE MOTOR AREAS ON THE OUTER SURFACE OF A MONKEY'S BRAIN.—(*Horsley and Schäfer.*)

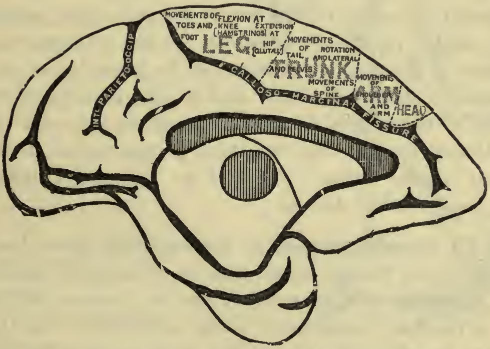

MOVEMENTS OF TOES AND FOOT
FLEXION AT KNEE (HAMSTRINGS)
EXTENSION AT HIP (GLUTEI)
LEG
MOVEMENTS OF TAIL AND PELVIS
ROTATION AND LATERAL MOVEMENTS OF SPINE
TRUNK
MOVEMENTS OF SHOULDER AND ARM
ARM
HEAD
INTL. PARIETO-OCCIP.
CALLOSO-MARGINAL FISSURE

FIG. 28.—DIAGRAM OF THE MOTOR AREAS ON THE MARGINAL CONVOLUTION OF A MONKEY'S BRAIN.—(*Horsley and Schäfer.*)

In the upper part are centers governing the movements of the *muscles of the opposite angle of the mouth* and of the *lower face.* The anterior portion of the lower two thirds controls the movements of the vocal cords, and may be regarded as a laryngeal center; the posterior portion governs the opening and shutting of the mouth and the protrusion and retraction of the tongue.

2. The *upper limb area* may be subdivided as follows: The upper part controls the movements of the shoulder; posteriorly and below this point are centers for the elbow; below and anteriorly, centers for the wrist and finger movements, while lowest and posteriorly, centers governing the thumb.
3. The *leg area* may be subdivided as follows: The anterior part, both on the mesial and lateral surfaces, contains centers governing the hip and thigh movements; in the posterior part are centers for the movements of the leg and toes. The center for the great toe has been located in the paracentral lobule.
4. The *trunk area,* situated largely on the mesial surface, contains anteriorly centers governing the rotation and arching of the spine, while posteriorly are found centers governing movements of the tail and pelvis.
5. The *head area,* or *area for visual direction,* contains centers excitation of which causes "opening of the eyes, dilatation of the pupils, and turning of the head to the opposite side, with conjugate deviation of the eyes to that side."

The centers of origin of the nerves for the ocular muscles lie in the gray matter of the aqueduct of Sylvius. Destruction of the gray matter at these points is followed by paralysis of the muscles of the opposite side of the body, and morbid growths, hemorrhages, or thrombi of the vessels of the part result in abnormal stimulation or in interference with the functions corresponding to the nature and extent of the lesion. Cerebral or Jacksonian epilepsy is a result of local cortical disease.

Center for Speech.—Pathologic investigations have demonstrated that the left third frontal convolution is of essential importance for speech. Adjoining this convolution are the centers controlling the motility of the lips, tongue, etc. In the majority of cases the speech centers are on the left side of the brain, though in exceptional cases they are on the right side, especially in left-handed persons. In deaf mutes this convolution is very imperfectly developed, while in monkeys it is quite rudimentary.

Lesions of the third frontal convolution on the left side, if the patient be right-handed, produce the various forms of *aphasia,* or the partial or complete loss of the power of articulate speech.

Aphasia is of many degrees and kinds. In *ataxic* aphasia the patient is unable to communicate his thoughts by words, there being an inability to execute the movements of the mouth, etc., necessary for speech. In *agraphic* aphasia there is an inability to execute the movements necessary for writing, though the mental processes are retained. In the ataxic form the lesion is in the third frontal convolution, and in the agraphic form it is in the arm center.

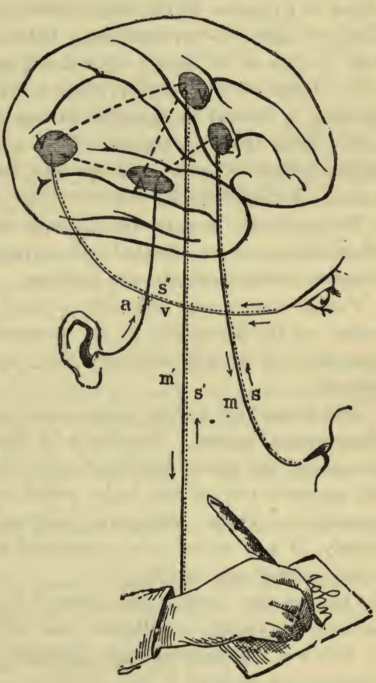


FIG. 29.

In *amnesic aphasia* there is a loss of the memory of words, the purest examples of which consist of the affections known as *word-deafness* and *word-blindness.* In word-deafness the patient can not understand vocal speech, though he is capable of hearing other sounds. This condition is associated with lesion of the first temporal convolution. In *word-blindness* the patient can not name a letter or a word printed or written, though he can see all other objects. This condition is associated with impairment of the visual centers.

Figure 29 will illustrate the conditions in the various forms of aphasia. Impressions are constantly passing from eye and ear to the visual and auditory centers and are there being registered. Commissural fibers connect these centers with the arm and speech centers, which in turn are connected by efferent fibers with the muscles of the hand and of the vocal apparatus. Muscular movements of the eye, hand, and mouth are also registered by means of the afferent fibers, s, s′, s″.

Sensor Centers.—These are the centers in which the afferent impulses are translated into conscious sensations. The most important are:

The *visual center,* located in the occipital lobe and especially in the cuneus. Unilateral destruction of this area results in *hemianopsia,* or blindness of the corresponding halves of the two retinæ. Destruction of both occipital lobes in man results in total blindness. Stimulation or irritation of the visual center causes *photopsia,* or hallucinations of sight, in corresponding halves of the retinæ. There have been instances of injury of these parts when sensations of color were abolished with preservation of those of space and light, thus showing a special localization of the color center. Recent experiments show that the centers of the two hemispheres are united, as ocular fatigue of an unused eye was found to be proportional to the fatigue of the exercised one.

The *auditory centers* are located in the temporosphenoid lobes. Word-deafness is associated with softening of these parts, and their complete removal results in deafness.

The *gustatory* and *olfactory centers* are located in the uncinate gyrus, on the inner side of the temporosphenoid lobes. There does not seem to be any differentiation, up to this time, of these two centers.

The center for tactile impressions was located by Ferrier in the hippocampal region. Horsley and Schäfer found that destructive lesions of the gyrus fornicatus were followed by hemianesthesia of the opposite side of the body, which was more or less marked and persistent. These observers conclude that the limbic lobe "is largely, if not exclusively, concerned in the appreciation of sensations, painful and tactile."

The *superior* and *middle frontal convolutions* appear to be the seats of the reason, intelligence, and will. Destruction of these parts is followed by proportional hebetude, without any impairment of sensation or motion.

THE SYMPATHETIC NERVE SYSTEM.

The **sympathetic nerve system** consists of a chain of ganglia connected by longitudinal nerve filaments, situated on each side of the spinal column, running from above downward. The two ganglionic cords are connected in the interior of the cranium by the ganglion of Ribes, on the anterior communicating artery, and terminate in the ganglion impar, situated at the top of the coccyx.

The chain of ganglia is divided into groups, and named according to the location in which they are found—viz., *cranial,* four in number; *cervical,* three; *thoracic,* twelve; *lumbar,* five; *sacral,* five; *coccygeal,* one. Each ganglion consists of a collection of *vesicular nervous* matter, bundles of non-medullated nerve-fibers, embedded in a capsule of connective tissue. The ganglia are reinforced by motor and sensory fibers from the cerebro-spinal nervous system.

The **ganglia** have distinct nerve-fibers, from which branches are distributed to the glands, arteries, and muscles, and to the cerebral and spinal nerves, many pass, also the visceral ganglia—*e. g.,* cardiac, semilunar, pelvic, etc.

Cephalic Ganglia.

1. The *ophthalmic* or *ciliary* ganglion is situated in the orbital cavity, posterior to the eyeball; it is of small size and of a reddish-gray color; receives filaments of communication from the motor oculi ophthalmic branch of the fifth pair, and the carotid plexus. Its filaments of distribution are the ciliary nerves, which consist of—
    - (*a*) *Motor* fibers for the circular fibers of the iris and ciliary muscle.
    - (*b*) *Sensor* fibers for the cornea, iris, and associated parts.
    - (*c*) *Vaso-motor* fibers for the blood-vessels of the choroid, iris, and retina.
    - (*d*) *Motor* fibers for the dilator fibers of the iris.
2. The *spheno-palatine* or Meckel's ganglion, triangular in shape, is situated in the sphenomaxillary fossa; receives filaments from the facial (Vidian nerve) and the superior maxillary branch of the fifth nerve. Its filaments of distribution pass to the gums, the soft palate and associated parts.
3. The *otic* or Arnold's ganglion is of small size, oval in shape, and situated beneath the foramen ovale; receives a motor filament from

the facial and sensor filaments from the glossopharyngeal and fifth nerves; sends filaments to the mucous membrane of the tympanic cavity and to the tensor tympani muscle.

4. The *submaxillary* ganglion, situated in the submaxillary gland, receives filaments from the chorda tympani, sensor filaments from the lingual branch of the fifth nerve, and filaments from the sympathetic. The chorda tympani nerve supplies *vaso-dilator* and *secretor* fibers to the submaxillary and sublingual glands. The fifth nerve endows the glands with sensibility, while the sympathetic supplies vaso-constrictor fibers to the blood-vessels of the glands.

Cervical Ganglia.

The *superior cervical* ganglion is fusiform in shape, of a grayish-red color, and situated opposite the second and third cervical vertebræ; it sends branches to form the carotid and cavernous plexuses, which branches follow the course of the carotid arteries to their distribution; also sends branches to join the glossopharyngeal and pneumogastric, to form the pharyngeal plexus.

The *middle cervical* ganglion, the smallest of the three, is occasionally absent; it is situated opposite the fifth cervical vertebra; sends branches to the superior and inferior cervical ganglia and to the thyroid artery.

The *inferior cervical* ganglion, irregular in form, is situated opposite the last cervical vertebra; it is frequently united with the first thoracic ganglion.

The *superior, middle,* and *inferior cardiac nerves,* arising from these cervical ganglia, pass downward and forward to form the deep and superficial cardiac plexuses located at the bifurcation of the trachea, from which branches are distributed to the heart, coronary arteries, etc.

The **thoracic ganglia** are usually twelve in number, and are placed against the heads of the ribs behind the pleura; they are small in size and gray in color; they communicate with the cerebrospinal nerves by two filaments, one of which is white, the other gray.

The *great splanchnic nerve* is formed by the union of branches from the sixth, seventh, eighth, and ninth ganglia; it passes through the diaphragm to the semilunar ganglion.

The *lesser splanchnic nerve* is formed by the union of filaments from the tenth and eleventh ganglia, and is distributed to the celiac plexus.

The *renal splanchnic nerve* arises from the last thoracic ganglion and terminates in the renal plexus.

The *semilunar ganglia,* the largest of the sympathetic system, are situated by the side of the celiac axis; they send radiating branches to form the *solar plexus;* from the various plexuses, nerves follow the gastric, splenic, hepatic, renal, etc., arteries, into the different abdominal viscera.

The **lumbar ganglia,** four in number, are placed upon the bodies of the vertebra; they give off branches, which unite to form the aortic lumbar plexus and the hypogastric plexus, and follow the blood-vessels to their terminations.

The **sacral** and **coccygeal ganglia** send filaments of distribution to all the blood-vessels of the pelvic viscera.

Properties and Functions.—The sympathetic nerve possesses both sensibility and the power of exciting motion, but these properties are much less decided than in the cerebro-spinal system. *Division* of the sympathetic nerve in the neck is followed by a vascular congestion of the parts above the section on the corresponding side, attended by an increase in the temperature; not only is there an increase in the amount of blood, but the rapidity of the blood current is very much accelerated and the blood in the veins becomes of a brighter color. *Galvanization* of the upper end of the divided nerve causes all the preceding phenomena to disappear; the congestion decreases, the temperature falls, and the venous blood becomes dark again.

The sympathetic exerts a similar influence upon the circulation of the limbs and the glandular organs; *destruction* of the first thoracic ganglion and division of the nerves forming the lumbar and sacral plexuses are followed by a dilatation of the vessels, an increased rapidity of the circulation, and an elevation of temperature in the anterior and posterior limbs; galvanization of the peripheral ends of these nerves causes all of these phenomena to disappear. Division of the splanchnic nerve causes a dilatation of the blood-vessels of the intestine.

These phenomena of the sympathetic nervous system are dependent upon the presence of vaso-motor nerves, which, under normal circumstances, exert a tonic influence upon the blood-vessels. These nerves, derived from the cerebro-spinal system and the medulla oblongata, leave the spinal cord by the *rami communicantes,* enter the sympathetic ganglia, and finally terminate in the muscular walls of the blood-vessels.

THE CRANIAL NERVES.

The cranial nerves come off from the base of the brain, pass through foramina in the walls of the cranium, and are distributed to the structures of the head, the face and in part to the organs of the thorax and abdomen.

According to the classification of Soemmering, there are twelve pairs of nerves, enumerating them from before backward, as follows—viz.:

First pair, or olfactory.
Second pair or optic.
Third pair, or motor oculi communis.
Fourth pair, or patheticus, trochlearis.
Fifth pair, or trigeminal.
Sixth pair, or abducens.
Seventh pair or facial, portio dura.
Eighth pair, or auditory, portio mollis.
Ninth pair, or glosso-pharyngeal.
Tenth pair, or pneumogastric.
Eleventh pair, or spinal accessory.
Twelfth pair, or hypoglossal.

The **cranial nerves** may also be classified physiologically, according to their function, into three groups:

1. Nerves of special sense—*e. g.,* olfactory, optic, auditory, gustatory (glosso-pharyngeal and chorda tympani).
2. Nerves of motion—*e. g.,* motor oculi, patheticus, small root of the trigeminal, facial, spinal accessory and hypoglossal.
3. Nerves of general sensibility—*e. g.,* large root of the trigeminal, the glosso-pharyngeal and the pneumogastric.

ORIGINS OF THE CRANIAL NERVES.

The *nerves of special sense* have their origin in neuro-epithelial cells in the sense organs with which they are connected.

The *nerves of motion* have their origin in nerve cells situated in the gray matter beneath the floor of the aqueduct of Sylvius and the floor of the fourth ventricle.

The *nerves of general sensibility* have their origin in the ganglia situated on their trunks.

First Pair. Olfactory.

The olfactory nerve is situated in the upper third of the nasal fossa. It consists of from 20 to 30 branches.

Origin.—From neuro-epithelial cells situated among the epithelial cells covering the mucous membrane. From these cells the nerve-fibers pass upward through foramina in the cribriform plate of the ethmoid bone and arborize around nerve-cells, in the olfactory bulb.

The Olfactory Tract.—The olfactory tract consists of both gray and white fibers which pass from their origin in the bulb, to the base of the cerebrum where it divides into three branches, viz., an *external white root,* which passes across the fissure of Sylvius to the middle lobe of the cerebrum; an *internal white root,* which passes also into the middle lobe; a *gray root,* which is in relation with the anterior lobe. The white fibers at least terminate around nerve-cells in the gray matter of the pre-callosal part of the gyrus fornicatus, the gyrus hippocampus and the gyrus uncinatus.

Properties.—The olfactory nerves do not give rise to either motor or sensor phenomena when stimulated. When stimulated at their periphery by odorous particles, nerve impulses are developed which, when conducted to the brain, evoke the sensation of smell. Destruction of the olfactory nerves, the bulb or tract, is followed by a loss of the sense of smell.

Function.—*Presides* over the sense of smell. Conducts impulses to the cerebrum which give rise to odorous sensations.

Second Pair. Optic.

Origin.—The optic nerve arises from large nerve-cells in the anterior part of the retina. From this origin the nerve-fibers turn backward and converge to form a well-defined bundle (the optic nerve) which passes out of the eyeball, through the orbit cavity as far as the sella turcica. At this point there is a union and partial decussation, in man at least, of the fibers, forming what is known as the *optic chiasm.* From the posterior portion of the chiasm there passes backward on either side a bundle of nerve-fibers, the *optic tract.* Each tract contains nerve-fibers which come from the temporal two thirds of the retina of the same side and the nasal third of the retina of the opposite side. The fibers of the optic tract arborize around nerve-cells in the external geniculate body, the pulvinar, and the anterior quadrigeminal body. By means of the optic radiation, the nerve-cells in these different ganglia are brought into relation with the visual center, the *cuneus*.

Properties.—The optic nerves are insensible to ordinary impressions, and convey only the *special impressions of light*. *Division* of one of the nerves is attended by complete blindness in the eye of the corresponding side.

Hemiopia and Hemianopsia.—Owing to the decussation of the fibers in the optic chiasm, *division* of the *optic tract* produces *loss* of *sight* in the *outer half* of the eye of the same side, and in the *inner half* of the eye of the opposite side, the blind part being separated from the normal part by a vertical line. The term hemiopia is applied to the loss of function or paralysis of the one half of the retina; as a result of this, there will be an obliteration of the field of vision on the opposite side to which the term hemianopsia is given. If, for example, the *right optic tract* be divided, there will be hemiopia in the outer half of the right eye and inner half of the left eye, thus causing *left lateral hemianopsia,* and as the two halves are affected which correspond in normal vision, the condition is known as *homonymous hemianopsia.* Lesion of the anterior part of the *optic chiasm* causes blindness in the inner half of the two eyes.

Functions.—Governs the sense of sight. Receives and conveys to the brain the nerve impulses made by ether vibrations and which give rise to the sensation of light.

The reflex movements of the iris are called forth by stimulation of the optic nerve. When light falls upon the retina, the nerve impulse developed is carried back to the tubercula quadrigemina, where it is transformed into a motor impulse, which then passes outward through the motor oculi nerve to the contractile fibers of the iris and diminishes the size of the pupil. The absence of light is followed by a dilatation of the pupil.

Third Pair. Motor Oculi Communis.

Origin.—From several groups of nerve-cells situated in the gray matter beneath the aqueduct of Sylvius.

Distribution.—From this origin the nerve-fibers pass forward and emerge from the cerebrum at the inner side of the crus cerebri. The nerve then passes forward, and enters the orbit through the sphenoid fissure, where it divides into a *superior branch* distributed to the *superior rectus* and *levator palpebræ* muscles; an *inferior* branch, sending branches to the *internal* and *inferior recti* and the *inferior oblique* muscles; filaments also pass into the *ciliary* or *ophthalmic* ganglion; from this ganglion the *ciliary nerves* arise, which enter the eyeball and are distributed to the *circular fibers of the iris* and the *ciliary muscle.* The third nerve also receives filaments from the cavernous plexus of the sympathetic and from the fifth nerve.

Properties.—Irritation of the root of the nerve produces contraction of the pupil, internal strabismus, and muscular movements of the eye, but no pain. *Division* of the nerve is followed by *ptosis* (falling of the upper eyelid); *external strabismus,* due to the unopposed action of the external rectus muscle; paralysis of the accommodation of the eye; *dilatation* of the pupil from paralysis of the circular fibers of the iris and ciliary muscle; and *inability* to *rotate* the eye, *slight protrusion,* and *double vision.* The images are crossed; that of the paralyzed eye is a little above that of the second, and its upper end inclined toward it.

Function.—Governs movements of the eyeball by innervating all the muscles except the external rectus and superior oblique, influences the movements of the iris, elevates the upper lid, influences the accommodation of the eye for distances. Can be called into action by (1) voluntary stimuli, (2) by reflex action through irritation of the optic nerve.

Fourth Pair. Patheticus.

Origin.—From nerve-cells situated in the gray matter beneath the aqueduct of Sylvius, just posterior to the last nucleus of the third nerve.

Distribution.—The nerve enters the orbital cavity through the sphenoid fissure, and is distributed to the *superior oblique* muscle; in its course it receives filaments from the ophthalmic branch of the fifth pair and the sympathetic.

Properties.—When the nerve is *irritated,* muscular movements are produced in the superior oblique muscle, and the pupil of the eye is turned *downward* and *outward.* Division or paralysis lessens the movements and rotation of the globe downward and outward. The diplopia consequent upon this paralysis is homonymous, one image appearing above the other. The image of the paralyzed eye is below, its upper end inclined toward that of the sound eye.

Function.—Governs the movements of the eyeball produced by the action of the superior oblique muscles.

Sixth Pair.* Abducens. Motor Oculi Externus.

Origin.—From nerve-cells situated beneath the upper half of the floor of the fourth ventricle.

Distribution.—From this origin the nerve passes into the orbit through the sphenoid fissure, and is distributed to the *external rectus* muscle. Receives filaments from the cervical portion of the sympathetic, through the carotid plexus, and spheno-palatine ganglion.

Properties.—When *irritated,* the *external rectus muscle* is thrown into convulsive movements and the eyeball is turned outward. When *divided* or *paralyzed,* this muscle is paralyzed, motion of the eyeball outward past the median line is impossible, and the homonymous diplopia increases as the object is moved outward past this line. The images are upon the same plane and parallel. Internal strabismus results because of the unopposed action of the internal rectus.

Function.—To innervate the external rectus muscle by which the eyeball is turned outward.

Fifth Pair. Trigeminal.

The fifth nerve consists of both afferent and efferent fibers which for the most part are separate and distinct. The afferent fibers constitute by far the major portion, the efferent fibers the minor portion of the nerve.

Origin of the Afferent Fibers.—The afferent fibers have their origin in nerve-cells in the Gasserian ganglion. From each cell a short process develops which soon divides into two branches, one of which passes centrally, the other peripherally. The centrally directed branches form the so-called large root; the peripherally directed branches collectively constitute the three main divisions of the nerve, viz.: the ophthalmic, the superior maxillary and the inferior maxillary.

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* The sixth nerve is considered in connection with the third and fourth nerves since they together constitute the motor apparatus by which the ocular muscles are excited to action.

Distribution.—The *centrally directed* branches enter the pons Varolii on its lateral aspect. After pursuing a short distance, these fibers arborize around nerve-cells in the gray matter of the pons and medulla.

The *peripherally directed* branches are distributed as follows:

1. The *ophthalmic branches* to the conjunctiva and skin of the upper eyelid, the cornea, the skin of the forehead and the nose, the lachrymal gland and the mucous membrane of the nose.
2. The *superior maxillary branches* to the skin and conjunctiva of the lower lid, the nose, the cheek and upper lip, the palate teeth of the upper jaw and the alveolar processes.
3. The *inferior maxillary branches* to the external auditory meatus, the side of the head, the mouth, the tongue, the teeth of the lower jaw, the alveolar processes and the skin of the lower part of the face.

Properties.—The trigeminal nerve, composed mainly of afferent fibers, is the most acutely sensitive nerve in the body, and endows all the parts to which it is distributed with general sensibility.

Irritation of the *large root,* or of any of its branches, will give rise to marked evidence of pain; the various forms of neuralgia of the head and face being occasioned by compression, disease, or exposure of some of its terminal branches.

Division of the large root within the cranium is followed at once by a complete abolition of all sensibility in the head and face, but is not attended by any loss of motion. The integument, the mucous membranes, and the eye may be lacerated, cut, or bruised, without the animal exhibiting any evidence of pain. At the same time the lachrymal secretion is diminished, the pupil becomes contracted, the eyeball is protruded, and the sensibility of the tongue is abolished.

The reflex movements of deglutition are also somewhat impaired, the impression of the food being unable to reach and excite the nerve center in the medulla oblongata.

Origin of the Efferent Fibers.—The efferent fibers have their origin in nerve-cells in the gray matter of the pons Varolii beneath the floor of the fourth ventricle.

Distribution.—The efferent fibers, known collectively as the small root, emerge from the side of the pons Varolii, pass forward beneath the ganglion of Gasser, beyond which they enter the inferior maxillary division. After a short course most of these fibers leave the common trunk and are distributed to the muscles of mastication, viz.: the temporal, the masseter, the internal and external pterygoid muscles. Other fibers are distributed to the mylohyoid muscle, the tensor palati and the tensor tympani muscles.

Properties.—*Stimulation* of the *small root* produces convulsive movements of the muscles of mastication; *section* of the root causes paralysis of these muscles, after which the jaw is drawn to the opposite side by the action of the opposing muscles.

The Influence of the Trigeminal on the Special Senses.—After division of the large root within the cranium, a disturbance in the nutrition of the special senses sooner or later manifests itself.

Sight.—In the course of twenty-four hours the *eye* becomes very vascular and inflamed, the cornea becomes opaque and ulcerates, the humors are discharged, and the eye is totally destroyed.

Smell.—The nasal mucous membrane swells up, becomes fungous, and is liable to bleed on the slightest irritation. The mucus is increased in amount, so as to obstruct the nasal passages; the sense of smell is finally abolished.

Hearing.—At times the hearing is impaired from disorders of nutrition in the middle ear and external auditory meatus.

Alteration in the nutrition of the special senses is not marked if the section is made posterior to the ganglion of Gasser and to the anastomosing filaments of the sympathetic, which join the nerves at this point; but if the ganglion be divided, these effects are very noticeable, owing to the section of the sympathetic filaments.

Function.—The trigeminal nerve, through its afferent fibers, endows all the parts of the head and face to which it is distributed with sensibility; through its efferent fibers it gives motion to the muscles of mastication, and to the tensor muscle of the palate and the tensor of the tympanic membrane; through anastomosing fibers from the sympathetic it influences the nutrition of the special senses.

Seventh Pair. Portio Dura. Facial Nerve.

Origin.—From a large nucleus of nerve-cells situated in the gray matter beneath the upper half of the floor of the fourth ventricle.

Distribution.—From this origin the nerve emerges from the lower border of the pons. It then passes into the internal auditory meatus in company with the nerve of Wrisberg, and then enters the aqueduct of Fallopius.

The nerve-fibers composing the nerve of Wrisberg have their origin in nerve-cells in the geniculata ganglion, situated on the facial just where it bends to enter the aqueduct of Fallopius. The centrally directed branches enter the medulla oblongata around the nerve-cells, in which they terminate; the peripherally directed branches enter the trunk of the facial.

In the aqueduct the facial gives off the following branches—viz.:

1. The *large petrosal nerve,* which passes forward to the *splenopalatine,* or Meckel's ganglion.
2. The *small petrosal nerve,* which passes to the *otic* ganglion.
3. The *tympanic branch,* which passes to the stapedius muscle and endows it with motion.
4. The *chorda tympani nerve,* which, after entering the posterior part of the tympanic cavity, passes forward between the malleus and incus, through the Glasserian fissure, and joins the lingual branch of the fifth nerve. It is then distributed to the mucous membrane of the anterior two thirds of the tongue and the submaxillary glands.

After emerging from the stylomastoid foramen, the facial nerve sends branches to the muscles of the ear, the occipitofrontalis, the digastric, the palatoglossi, and palatopharyngei; after which it passes through the parotid gland and divides into the *temporofacial* and *cervicofacial* branches, which are distributed to the superficial muscles of the face—viz., occipitofrontalis, corrugator supercilii, orbicularis palpebrarum, levator labii superioris et alæque nasi, buccinator, levator anguli oris, orbicularis oris, zygomatici, depressor anguli oris, platysma myoides, etc.

Properties.—Undoubtedly a motor nerve at its origin, but in its course receives sensitive filaments from the fifth pair and the pneumogastric.

Irritation of the nerve, after its emergence from the stylomastoid foramen, produces convulsive movements in all the superficial muscles of the face. *Division* of the nerve at this point causes paralysis of these muscles on the side of the section, constituting *facial paralysis,* the phenomena of which are a relaxed and immobile condition of the same side of the face; the eyelids remain open, from paralysis of the orbicularis palpebrarum; the act of winking is abolished; the angle of the mouth droops, and saliva constantly drains away; the face is drawn over to the second side; the face becomes distorted upon talking or laughing; mastication is interfered with, the food accumulating between the gums and cheek, from paralysis of the buccinator muscle; fluids escape from the mouth in drinking; articulation is impaired, the labial sounds being imperfectly pronounced.

Properties and Functions of the Branches Given off in the Aqueduct of Fallopius.

1. The *large petrosal*, when stimulated, gives rise to a dilatation of the blood-vessels and a secretion from the mucous membrane of nose, soft palate, upper part of the pharynx, roof of the mouth, and gums. It therefore contains vaso-motor and secretor fibers, which are in relation with the spheno-palatine ganglion.
2. The *tympanic* branch causes the stapedius muscle to contract.
3. The *chorda tympani* influences the circulation of the blood around and the secretion of saliva from the submaxillary glands, and through the nerve of Wrisberg governs the sense of taste in the anterior two thirds of the tongue. *Galvanization* of the chorda tympani dilates the blood-vessels, increases the quantity and rapidity of the stream of blood, and increases the secretion of saliva. *Division* of the nerve is followed by contraction of the vessels, an arrest of the secretion, and a diminution of the sense of taste on the same side. It therefore contains vaso-motor, secretor and gustatory nerve-fibers.

Function.—The facial is the nerve of expression, and coördinates the muscles employed to delineate the various emotions, influences the sense of taste and the secretions of the submaxillary and sublingual glands.

Eighth Pair. Portio Mollis. Auditory Nerve.

The eighth nerve consists of two portions, a *cochlear* or *auditory* and a *vestibular* or *equilibratory*.

Origin.—The cochlear portion has its origin in the bipolar nerve-cells of the spiral ganglion located in the spiral canal near the base of the osseous lamina spiralis. The vestibular portion has its origin in the bipolar nerve-cells of the ganglion of Scarpa, located in the internal auditory meatus.

Distribution.—The common trunk of the eighth nerve, consisting of both the cochlear and vestibular portions, emerge from the internal auditory meatus after which it passes backward and inward as far as the lateral aspect of the pons, where the two main divisions again separate. The cochlear portion passes to the outer side of the restiform body; the vestibular portion passes to the inner side of the restiform body to the dorsal portion of the pons. After entering the pons the fibers composing both portions come into histologic relations with different groups of nerve-cells.

Properties.—Stimulation of the cochlear nerve is unattended by either motor or sensor phenomena. Division of the nerve is followed by a loss of hearing. Destruction of the semicircular canal, involving a lesion of the vestibular nerves at their origin, is followed by a loss of the power of coördination and equilibration.

Functions.—The cochlear nerve presides over the sense of hearing. It carries to the brain the nerve impulses produced by the impact of atmospheric vibrations on the ear, and which give rise to the sensation of sound. The vestibular nerve carries nerve impulses to the brain, which excite certain reflex adaptive movements by which the equilibrium of the body is maintained.

Ninth Pair. Glossopharyngeal.

Origin.—From nerve-cells in the ganglia situated on the trunk of the nerve near the medulla oblongata—viz., the petrosal ganglion and the jugular ganglion. From these cells a single branch emerges, which soon divides into two branches, one of which passes centrally, the other peripherally. The centrally directed branches enter the medulla oblongata, where they terminate around nerve-cells. The peripherally directed branches collectively form the two main divisions from which the nerve takes its name.

The glossopharyngeal also contains efferent nerve-fibers, which have their origin in nerve-cells beneath the floor of the fourth ventricle.

Distribution.—The trunk of the nerve passes downward and forward, receiving near the jugular ganglion fibers from the facial and pneumogastric nerves. It divides into two large branches, one of which is distributed to the base of the tongue, the other to the pharynx. In its course it sends filaments to the otic ganglion; a tympanic branch which gives sensibility to the mucous membrane of the fenestra rotunda, fenestra ovalis, and Eustachian tube; lingual branches to the base of the tongue; palatal branches to the soft palate, uvula, and tonsils; pharyngeal branches to the mucous membrane of the pharynx.

Properties.—*Irritation* of the roots at their origin calls forth evidences of pain; it is, therefore, a sensor nerve, but its sensibility is not so acute as that of the trigeminal. *Irritation* of the trunk after its exit from the cranium produces contraction of the muscles of the palate and pharynx, owing to the presence of motor fibers.

Division of the nerve abolishes sensibility in the structures to which it is distributed and impairs the sense of taste in the posterior third of the tongue (see Sense of Taste).

Function.—Governs the sensibility of the pharynx, presides partly over the sense of taste, and controls reflex movements of deglutition and vomiting.

Tenth Pair. Pneumogastric. Vagus.

Origin.—From nerve-cells situated along the trunk of the nerve near the medulla oblongata—viz.: the jugular and the plexiform ganglia. From the nerve-cells in these ganglia a short process emerges which soon divides into two branches one of which passes centrally, the other peripherally. The central branches enter the medulla oblongata, where they terminate around nerve-cells; the peripheral branches collectively form the main portion of the trunk of the nerve.

The pneumogastric also contains efferent fibers which have their origin in nerve-cells beneath the floor of the medulla oblongata. It also receives motor fibers from the spinal accessory, the facial, the hypoglossal and the anterior branches of the two upper cervical nerves.

Distribution.—As the nerve passes down the neck it sends off the following main branches:

1. *Pharyngeal nerves,* which assist in forming the pharyngeal plexus, which is distributed to the mucous membrane and to the muscles of the pharynx.
2. *Superior laryngeal nerve,* which enters the larynx through the thyrohyoid membrane, and is distributed to the mucous membrane lining the interior of the larynx, and to the cricothyroid muscle and the inferior constrictor of the pharynx. The '*depressor nerve,*"

found in the rabbit, is formed by the union of two branches, one from the superior laryngeal, the other from the main trunk; it passes downward to be distributed to the heart.

3. *Inferior laryngeal,* which sends its ultimate branches to all the intrinsic muscles of the larynx except the cricothyroid, and to the inferior constrictor of the pharynx.
4. *Cardiac* branches given off from the nerve throughout its course, which unite with the sympathetic fibers to form the cardiac plexus, to be distributed to the heart.
5. *Pulmonary branches,* which form a plexus of nerves, and are distributed to the bronchi and their ultimate terminations, the lobules and air-cells.

From the right pneumogastric nerve branches are distributed to the mucous membrane and muscular coats of the stomach and intestines, and to the liver, spleen, kidneys, and suprarenal capsules.

Properties.—At its origin the pneumogastric nerve is sensory, as shown by direct irritation or galvanization, though its sensibility is not very marked. In its course it exhibits motor properties, from anastomosis with motor nerves.

The *pharyngeal branches* assist in giving sensibility to the mucous membrane of the pharynx, and influence reflex phenomena of deglutition through motor fibers which they contain, derived from the spinal accessory.

The *superior laryngeal* nerve endows the upper portion of the larynx with sensibility; protects it from the entrance of foreign bodies; by conducting impressions to the medulla, excites the reflex movements of deglutition and respiration; through the motor filaments it contains, produces contraction of the cricothyroid muscle. *Division* of the *"depressor nerve"* and *galvanization* of the central end retard and even arrest the pulsations of the heart, and by depressing the vaso-motor center, diminish the pressure of blood in the large vessels, by causing dilatation of the intestinal vessels through the splanchnic nerves.

The *inferior laryngeal* contains, for the most part, motor fibers from the spinal accessory. When *irritated,* produces movement in the laryngeal muscles. When *divided,* is followed by paralysis of these muscles, except the cricothyroid, impairment of phonation, and an embarrassment of the respiratory movements of the larynx, and, finally, death from suffocation.

The *cardiac branches,* through filaments derived from the spinal accessory, or possibly from the medulla oblongata direct, exert a direct inhibitory action upon the heart. *Division* of the pneumogastrics in the neck is followed by increased frequency of the heart's action. *Galvanization* of the peripheral ends diminishes the heart's pulsations, and, if sufficiently powerful, arrests it in diastole.

The *pulmonary branches* give sensibility to the bronchial mucous membrane and govern the movements of respiration. *Division* of both pneumogastrics in the neck diminishes the frequency of the respiratory movements, which may fall as low as four to six a minute; death usually occurs in from five to eight days. *Feeble galvanization* of the central ends of the divided nerves accelerates respiration; *powerful galvanization* retards, and may even arrest, the respiratory movements.

The *gastric branches* give sensibility to the mucous coat, and through motor or efferent fibers give motion to the muscular coat of the stomach. They influence the secretion of gastric juice, and aid the process of digestion.

The *hepatic branches,* probably through anastomosing sympathetic filaments, influence the secretion of bile and the glycogenic function of the liver; *division* of the pneumogastrics in the neck produces congestion of the liver, diminishes the density of the bile, and arrests the glycogenic function; *galvanization* of the central ends exaggerates the glycogenic function and makes the animal diabetic.

The *intestinal branches* give sensibility and motion to the small intestines.

Function.—A great sensor nerve, which, through filaments from motor sources, influences deglutition, the action of the heart, the circulatory and respiratory systems, voice, the secretions of the stomach, intestines, and various glandular organs, and the contraction of the walls of the stomach and intestines.

Eleventh Pair. Spinal Accessory.

The spinal accessory nerve consists of two distinct portions, the medullary or bulbar, and the spinal.

Origin.—The *medullary* portion has its origin in nerve-cells in the lower part of the nucleus ambiguous, located beneath the floor of the fourth ventricle. From this origin the nerve-fibers pass forward and emerge from the medulla oblongata on its lateral aspect.

The *spinal* portion has its origin in nerve-cells located in the lateral gray matter of the spinal cord as far down as the fifth cervical nerve. From this origin the nerve-fibers pass to the surface of the cord to emerge between the ventral and dorsal roots in from six to eight filaments, after which they unite to form a well-defined nerve. It then passes into the cranial cavity through the foramen magnum and unites with the medullary portion.

Distribution.—After the union the common trunk emerges from the cranial cavity through the jugular foramen and after sending branches to the pneumogastric and receiving others in turn from the pneumogastric as well as from the upper cervical nerves it divides into two branches—viz.:

1. An *internal* or *anastomotic* branch which soon enters the trunk of the pneumogastric nerve. The fibers of this branch are ultimately distributed to some of the pharyngeal muscles; to all of the muscles of the larynx by way of the laryngeal branches of the vagus nerve, and, according to most authorities, to the heart.
2. An *external* branch consisting chiefly of the accessory fibers from the spinal cord. It is distributed to the sterno-cleido-mastoid and trapezius muscles.

Properties.—At its origin it is a purely *motor* nerve, but in its course it exhibits some sensibility, due to the presence of anastomosing fibers.

Destruction of the *medullary root—e. g.,* tearing it from its attachment by means of forceps, impairs the action of the muscles of deglutition and destroys the power of producing vocal sounds from paralysis of the laryngeal muscles, without, however, interfering with the respiratory movements of the larynx, these being controlled by other motor nerves. The normal rate of movement of the heart is increased by destruction of the medullary root.

Irritation of the external branch throws the trapezius and sternomastoid muscles into convulsive movements, though *section* of the nerve does not produce complete paralysis, as they are also supplied with motor influence from the cervical nerves. The sternomastoid and trapezius muscles perform movements antagonistic to those of respiration, fixing the head, neck, and upper part of the thorax, and delaying the expiratory movement during the acts of pushing, pulling, straining, etc., and in the production of a prolonged vocal sound, as in singing. When the *external* branch alone is divided, in animals, they experience shortness in breath during exercise, from a want of coördination of the muscles of the limbs and respiration; and while they can make a vocal sound, it can not be prolonged.

Function.—Governs phonation by its influence upon the muscles regulating the position and tension of the vocal bands; influences the movements of deglutition, inhibits the action of the heart, and controls certain respiratory movements associated with sustained or prolonged muscular efforts and phonation.

Twelfth Pair. Hypoglossal or Sublingual.

Origin.—From nerve-cells situated deep in the substance of the medulla oblongata, on a level with the lowest portion of the floor of the fourth ventricle. From this origin the fibers pass forward and emerge from the medulla in the groove between the anterior pyramid and the olivary body.

Distribution.—The trunk formed by the union of the different filaments passes out of the cranial cavity through the anterior condyloid foramen. After emerging from the cranium, it sends filaments to the sympathetic and pneumogastric; it anastomoses with the lingual branch of the fifth pair, and receives and sends filaments to the upper cervical nerves. The nerve is finally distributed to the sternohyoid, sternothyroid, omohyoid, thyrohyoid, styloglossi, hyoglossi, geniohyoid, geniohyoglossi, and the intrinsic muscles of the tongue.

Properties.—A purely *motor* nerve at its origin, but derives sensibility outside the cranial cavity from anastomosis with the cervical pneumogastric, and fifth nerves.

Irritation of the nerve gives rise to convulsive movements of the tongue and slight evidences of sensibility.

Division of the nerve abolishes all movements of the tongue and interferes considerably with the act of deglutition.

When the hypoglossal nerve is involved in hemiplegia, the tip of the tongue is directed to the paralyzed side when the tongue is protruded, owing to the unopposed action of the geniohyoglossus on the sound side.

Articulation is considerably impaired in paralysis of this nerve, great difficulty being experienced in the pronunciation of the consonantal sounds.

Mastication is performed with difficulty, from inability to retain the food between the teeth until it is completely triturated.

Function.—Governs all the movements of the tongue and influences the functions of mastication, deglutition and articulation.

THE SENSE OF TOUCH.

The **sense of touch** is a modification of general sensibility, and is located in the skin, which is especially adapted for this purpose on account of the number of nerves and papillary elevations it possesses. The structures of the skin and the modes of termination of the sensory nerves have already been considered.

The **tactile sensibility** varies in acuteness in different portions of the body, being most marked in those regions in which the tactile corpuscles are most abundant—*e. g.*, the palmar surface of the third phalanges of the fingers and thumb.

The *relative sensibility* of different portions of the body has been ascertained by means of a pair of compasses: the points of the instrument being guarded by cork, it was then determined how closely they could be brought together, and yet be felt at two different points. The following are some of the measurements:

Point of tongue	½ of a line.
Palmar surface of third phalanx	1 line.
Red surface of lips	2 lines.
Palmar surface of metacarpus	3 "
Tip of the nose	3 "
Part of lips covered by skin	4 "
Palm of hand	5 "
Lower part of forehead	10 "
Back of hand	14 "
Dorsum of foot	18 "
Middle of the thigh	30 "

The sense of touch communicates to the mind the idea of *resistance* only, and the varying degrees of resistance offered to the sensory nerves enable us to estimate, with the aid of the muscular sense, the qualities of *hardness* or *softness* of external objects. The idea of *space* or *extension* is obtained when the sensory surface or the external object changes its place in regard to the other; the *character* of the surface, its *roughness* or *smoothness,* is estimated by the impressions made upon the tactile papillæ.

Appreciation of Temperature.—The general surface of the body is more or less sensitive to differences of temperature, though this sensation is separate from that of touch; whether there are nerves especially adapted for the conduction of this sensation has not been fully determined. Under pathologic conditions, however, the sense of touch may be abolished, while the appreciation of changes in temperature may remain normal.

The cutaneous surface varies in its sensibility to temperature in different parts of the body, and depends, to some extent, upon the thickness of the skin, exposure, habit, etc.; the inner surface of the elbow is more sensitive to changes in temperature than the outer portion of the arm; the left hand is more sensitive than the right, the mucous membrane less so than the skin.

Excessive heat or cold has the same effect upon the sensibility; the temperatures most readily appreciated are those between 50° F. and 115° F.

The sensations of *pain* and *tickling* appear to be conducted to the brain, also, by nerves different from those of touch; in abnormal conditions the appreciation of pain may be entirely lost while touch remains unimpaired.

THE SENSE OF TASTE.

The **sense of taste** is localized mainly in the mucous membrane covering the superior surface of the tongue.

The **tongue** is situated in the floor of the mouth; its base is directed backward and is connected with the hyoid bone and by numerous muscles with the epiglottis and soft palate; its apex is directed forward against the posterior surface of the teeth.

The *substance* of the tongue is made up of intrinsic muscle-fibers, the *linguales;* it is attached to surrounding parts, and its various movements are performed by the extrinsic muscles—*e. g.,* stylo-glossus, geniohyoglossus, etc.

The *mucous membrane* covering the tongue is continuous with that lining the commencement of the alimentary canal, and is furnished with vascular and nervous papillæ.

The *papillæ* are analogous in their structure to those of the skin, and are distributed over the dorsum of the tongue, giving it its characteristic roughness.

There are three principal varieties—

1. The *filiform papillæ* are most numerous, and cover the anterior two thirds of the tongue; they are conic or filiform in shape, often prolonged into filamentous tufts, of a whitish color, and covered by horny epithelium.
2. The *fungiform papillæ* are found chiefly at the tip and sides of the tongue; they are larger than the preceding, and may be recognized by their deep red color.
3. The *circumvallate papillæ* are rounded eminences from eight to ten in number, situated at the base of the tongue, where they form a V-shaped figure. They are quite large, and consist of a central projection of mucous membrane, surrounded by a wall, or circumvallation, from which they derive their name.

The **taste-beakers,** supposed to be the true organs of taste, are flask-like bodies, ovoid in form, about $\frac{1}{300}$ of an inch in length, situated in the epithelial covering of the mucous membrane, on the circumvallate papillæ. They consist of a number of fusiform, narrow cells, which are curved so as to form the walls of this flask-like body; in the interior are elongated cells, with large, clear nuclei, the *taste-cells.*

Nerves of Taste.—The *chorda tympani* nerve, a branch of the facial, after leaving the cavity of the tympanum, joins the third division of the fifth nerve between the two pterygoid muscles, and then passes forward in the lingual branches, to be distributed to the mucous membrane of the anterior two thirds of the tongue. Division or disease of this nerve is followed by a *loss of taste* in the part to which it is distributed.

The *glossopharyngeal* enters the tongue at the posterior border of the hyoglossus muscle, and is distributed to the mucous membrane of the base and sides of the tongue, fauces, etc.

The *lingual branch of the trifacial* nerve endows the tongue with general sensibility; the *hypoglossal* endows it with motion.

The *nerves of taste* in the superficial layer of the mucous membrane form a fine plexus, from which branches pass to the epithelium and penetrate it; others enter the taste-beakers, and are directly connected with the taste-cells.

The *seat* of the sense of taste has been shown by experiment to be the whole of the mucous membrane over the dorsum of the tongue, soft palate, fauces, and upper part of the pharynx.

The **sense of taste** enables us to distinguish the savor of substances introduced into the mouth, which faculty is different from tactile sensibility. The sapid qualities of substances appreciated by the tongue are designated as bitter, sweet, alkaline, sour, salt, etc.

The **essential conditions** for the production of the impressions of taste are:

1. A state of solubility of the food.
2. A free secretion of the saliva, and
3. Active movements on the part of the tongue, exciting pressure against the roof of the mouth, gums, etc., thus aiding the solution of various articles and their osmosis into the lingual papillæ.

Sapid substances, when in a state of solution, pass into the interior of the taste-beakers, and come into contact, through the medium of the taste-cells, with the terminal filaments of the gustatory nerves.

THE SENSE OF SMELL.

The **sense of smell** is located in the mucous membrane lining the upper part of the nasal cavity, in which the olfactory nerves are distributed.

The **nasal fossæ** are two cavities, irregular in shape, separated by the vomer, the perpendicular plate of the ethmoid bone, and the triangular cartilage. They open anteriorly and posteriorly by the anterior and posterior nares, the latter communicating with the pharynx. They are lined by mucous membrane, of which the only portion capable of receiving odorous impressions is the part lining the upper one third of the fossæ.

The olfactory nerves, the olfactory bulb and tracts, unite the olfactory epithelium with the cortical areas of smell in the cerebrum.

In animals which possess an acute sense of smell there is a corresponding increase in the development of the olfactory bulbs.

The **essential conditions** for the sense of smell are—

1. A special nerve center capable of receiving impressions and transforming them into odorous sensations.
2. Emanations from bodies which are in a gaseous or vaporous condition.
3. The odorous emanations must be drawn freely through the nasal fossæ; if the odor be very faint, a peculiar inspiratory movement is made, by which the air is forcibly brought into contact with the olfactory filaments. The secretions of the nasal fossæ probably dissolve the odorous particles.

Various substances, as ammonia, horseradish, etc., excite the sensibility of the mucous membrane; this must be distinguished from the perception of true odors.

THE SENSE OF SIGHT.

The Eyeball.—The eyeball, or organ of vision, is situated at the fore part of the orbital cavity and is supported by a cushion of fat; it is protected from injury by the bony walls of the cavity, the lids, and the lashes, and is so situated as to permit of an extensive range of vision. The eyeball is loosely held in position by a fibrous membrane, the *capsule of Tenon,* which is attached on the one hand to the eyeball itself and on the other to the walls of the cavity. Thus suspended, the eyeball is capable of being moved in any direction by the contraction of the muscles attached to it.

Structure.—The eyeball is spheroid in shape and measures about $\frac{9}{10}$ of an inch in its anteroposterior diameter, and a little less in its transverse diameter. When viewed in profile, it is seen to consist of the segments of two spheres, of which the posterior is the larger, occupying five sixths, and the anterior the smaller, occupying one sixth, of the ball.

The eye is made up of several membranes, concentrically arranged, within which are inclosed the refracting media essential to vision. These membranes, enumerated from without inward, are—

1. The sclerotic and cornea.
2. The choroid and iris.
3. The retina.

The refracting media are the aqueous humor, the crystalline lens, and the vitreous humor.

The Sclerotic and Cornea.—The sclerotic is the opaque fibrous membrane covering the posterior five sixths of the ball. It is composed of connective tissue arranged in layers, which run both transversely and longitudinally; it is pierced posteriorly by the optic nerve about $\frac{1}{10}$ of an inch internal to the optic axis. The sclerotic, by its density, gives form to the eye and protects the delicate structures within it, and serves for the attachment of the muscles by which the ball is moved.

The cornea is a transparent non-vascular membrane covering the anterior one sixth of the eyeball. It is nearly circular in shape and is continuous at the circumference with the sclerotic, from which it can not be separated. The substance of the cornea is made up of thin layers of delicate, transparent fibrils of connective tissue, more or less united; between these layers are found a number of intercommunicating lymph-spaces, lined by endothelium, which are in connection with lymphatics. Leukocytes or lymph-corpuscles are often found in these spaces. The anterior surface of the cornea is covered by several layers of nucleated epithelium, which rest upon a structureless membrane known as the *anterior elastic lamina.* The posterior surface is covered by a similar membrane, the membrane of Descemet, which at its periphery becomes continuous with the iris; it is also covered by a layer of epithelial cells. At the junction of the cornea and sclerotic is found a circular groove, the *canal of Schlemm.*

The **choroid,** the **iris,** the **ciliary muscle,** and the **ciliary processes** together constitute the second or middle coat of the eyeball.

The choroid is a dark brown membrane which extends forward nearly to the cornea, where it terminates in a series of folds, the *ciliary processes.* In its structure the choroid is highly vascular, consisting of both arteries and veins. Externally it is connected with the sclerotic by connective tissue; internally it is lined by a layer of hexagonal pigment cells, which, though usually classed as belonging to the choroid, is now known to belong, embryologically and physiologically, to the retina. From without inward may be distinguished the following layers:

1. The lamina suprachoroidea.
2. The elastic layer of Sattler, consisting of two endothelial layers.
3. The chorio-capillaris, choroid proper, or membrane of Ruysch—a thick, elastic network of arterioles and capillaries lying within the outer layer of veins and arteries called the venæ vorticosæ.

4. The lamina vitrea, or internal limiting membrane.

The choroid with its contained blood-vessels bears an important relation to the nutrition of the eye; it provides for the blood-supply and for drainage from the body of the eye, and presents a uniform and high temperature to the retina.

The *iris* is the circular variously colored membrane placed in the anterior portion of the eye just behind the cornea. It is perforated a little to the nasal side of the center by a circular opening, the *pupil.* The outer or circumferential border is connected with the cornea, ciliary muscle, and ciliary processes; the free inner edge forms the boundary of the pupil, the size of which is constantly changing. The framework of the iris is composed of connective-tissue blood-vessels, muscle-fibers and pigmented connective-tissue corpuscles. The anterior surface is covered with a layer of epithelial cells continuous with those covering the posterior surface of the cornea; the posterior surface is lined by a limiting membrane bearing pigment epithelial cells continuous with those of the choroid. The various colors which the iris assumes in different individuals depend upon the quantity and disposition of the pigment granules.

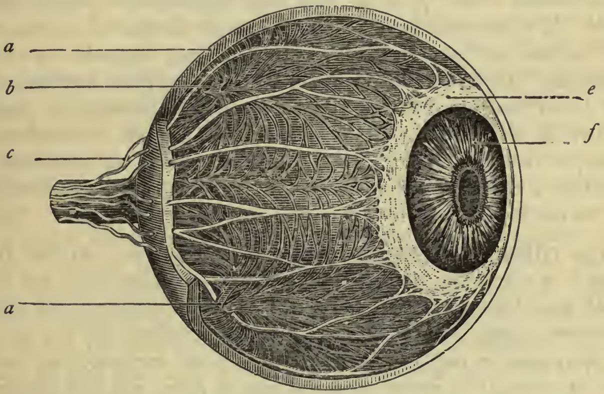

Fig. 30.—Sclerotic Coat removed to show Choroid Ciliary Muscle, and Nerves.—(*From Holden's "Anatomy."*)

a. Sclerotic coat. *b.* Veins of the choroid. *c.* Ciliary nerves. *d.* Veins of the choroid. *e.* Ciliary muscle. *f.* Iris.

The muscle-fibers of the iris, which are of the non-striated variety, are arranged in two sets—the sphincter and dilatator.

The *sphincter pupillæ* is a circular, flat band of muscle-fibers surrounding the pupil close to its posterior surface; by its contraction and relaxation the pupil is diminished or increased in size. The *dilatator pupillæ* consists of a thin layer of fibers arranged in a radiate manner; at the margin of the pupil they blend with those of the sphincter muscle, while at the outer border they arch to form a circular muscular layer.

The *ciliary muscle* is a gray, circular band, consisting of unstriped muscle-fibers about $\frac{1}{10}$ of an inch long running from before backward. It is attached anteriorly to the inner surface of the sclerotic and cornea, and posteriorly to the choroid coat opposite the ciliary processes. At the anterior border of the radiating fibers and internally are found bundles of circular muscle-fibers, constituting the *annular muscle* of Müller. The ciliary muscle thus consists of two sets of fibers, a radiating and a circular, both of which are concerned in effecting a change in the convexity of the lens in the accommodation of the eye to near vision.

The **retina** forms the internal coat of the eye. In the fresh state it is a delicate, transparent membrane of a pink color, but after death soon becomes opaque; it extends forward almost to the ciliary processes, where it terminates in an indented border, the *ora serrata.* In the posterior part of the retina, at a point corresponding to the axis of vision, is a yellow spot, the *macula lutea,* which is somewhat oval in shape and tinged with yellow pigment. It presents in its center a depression, the *fovea centralis,* corresponding to a decrease in thickness of the retina; about $\frac{1}{10}$ of an inch to the inner side of the macula is the point of entrance of the optic nerves. The *arteria centralis retinæ* pierces the optic nerve near the sclerotic, runs forward in its substance, and is distributed in the retina as far forward as the ciliary processes.

The retina is remarkably complex, consisting of ten distinct layers, from within outward, supported by connective tissue. These are as follows—viz.:

1. Membrana limitans interna.
2. Fibers of optic nerve.
3. Layers of ganglionic corpuscles.
4. Molecular layer.
5. Internal granular layer.

6. Molecular layer.
7. External granular layer.
8. Membrana limitans externa.
9. Jacobson's membrane, or layer of rods and cones.
10. The layer of pigment cells.

The most important of these, however, is the layer of rods and cones in the external portion of the retina. The rods are straight, elongated cylinders extending through the entire thickness of Jacobson's membrane. They consist of an external portion, which is clear, homogeneous, and highly refracting, and of an internal portion, which is slightly granular and less refractive; the outer end of each rod is in direct contact with the pigment epithelium lining the choroid, while the inner end, tapering to a fine thread, pierces the external limiting membrane and passes into the external granular layer. The cones consist also of two portions, the inner of which is somewhat thicker than the rod and rests upon the limiting membrane; the outer portion tapers to a fine point, which is known as the cone-style. The cones, as a rule, are somewhat shorter than the rods. The proportion of rods to cones varies in different parts of the retina, though there are on an average about fourteen rods to one cone. In the macula lutea, where vision is most acute, the rods are almost entirely absent, cones alone being present. All the retinal elements at this point are changed. The nerve-fiber layer is absent, the axis-cylinders radiating in such a manner as to leave the spot free from their covering. The remaining layers are all thinned and the stroma is reduced to a minimum. The optic nerve, after passing forward from the brain, penetrates in succession the sclerotic, choroid, and retina; the nerve-fibers then spread out over the anterior surface of the retina and become connected with the large ganglionic cells, the third layer of the retina.

The number of optic nerve-fibers in the retina is estimated to be about 800,000, and for each fiber there are about seven cones, one hundred rods, and seven pigment cells. The points of the rods and cones are directed toward the choroid, or away from the entering light, and dip into the pigment layer. They, with the pigment layer, are the intermediating elements in the change of the ethereal vibrations into nerve force; out of these nerve vibrations the brain fashions the sensations of light, form, and color.

The *vitreous humor,* which supports the retina, is the largest of the refracting media; it is globular in form and constitutes about four fifths of the ball; it is hollowed out anteriorly for the reception of the crystalline lens. The outer surface of the vitreous is covered by a delicate, transparent membrane, termed the *hyaloid membrane,* which serves to maintain its globular form.

The *aqueous humor,* found in the anterior chamber of the eye, is a clear alkaline fluid, having a specific gravity of 1003–1009. It is secreted most probably by the blood-vessels of the iris and ciliary processes. It passes from the interior of the eye, through the canal of Schlemm and the meshes at the base of the iris, into the anterior circular vein.

The *crystalline lens,* inclosed within its capsule, is a transparent bicovex body, situated just behind the iris and resting in the depression in the anterior part of the vitreous. The two convexities are not quite alike, the curvature of the posterior surface being slightly greater than that of the anterior. The lens measures about ⅓ of an inch in the transverse diameter and ⅕ of an inch in the antero-posterior diameter.

The *suspensory ligament,* by which the lens is held in position, is a firm, transparent membrane, united to the ciliary processes. A short distance beyond its origin it splits into two layers, the anterior of which is inserted into the capsule of the lens and blends with it; the posterior, passing inward behind the lens, becomes united to its capsule. The anterior layer presents a series of foldings, *zone of Zinn,* which are inserted into the intervals of the folds of the ciliary processes. The triangular space between the two layers is the canal of Petit.

Blood-vessels and Nerves.—The structures composing the eyeball are supplied with blood by the long and short ciliary arteries, branches of the ophthalmic; they pierce the sclerotic at various points and are ultimately distributed to all tissues within the ball.

The nerve-supply comes largely from the ophthalmic or ciliary ganglion. This is a small body, situated in the posterior part of the orbit; it receives motor fibers from a branch of the motor oculi, or third nerve; a sensory branch from the ophthalmic division of the fifth nerve, and fibers from the cavernous plexus of the sympathetic. From the anterior border of the ganglion proceed the ciliary nerves, which, entering the eyeball, endow its structures with motion and sensation.

The Eyeball a Living Camera Obscura.—The eyeball may be compared in a general way to a camera obscura. The anatomic arrangement of its structures reveals many points of similarity. The sclerotic and choroid may be compared with the walls of the chamber; the combined refractive media, cornea, aqueous humor, lens, and vitreous humor, to the lens for focusing the rays of light; the retina, to the sensitive plate receiving the image formed at the focal point; the iris, to the diaphragm, which, by cutting off the marginal rays, prevents spheric aberration and at the same time regulates the amount of light entering the eye; the ciliary muscle, to the adjusting screw, by which distinct images are thrown upon the retina in spite of varying distances of the object from which the light rays emanate. The structures just enumerated are those essential for normal vision.

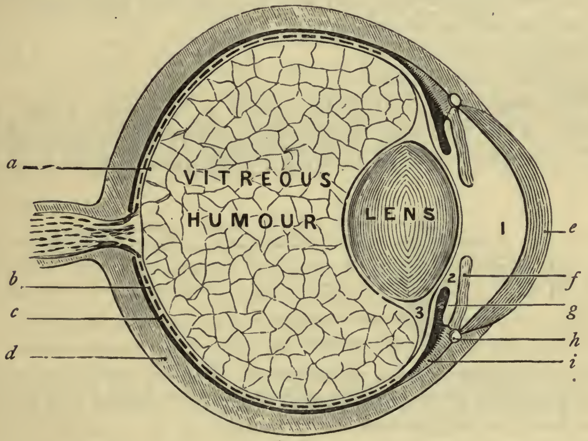

FIG. 31.—DIAGRAM OF A VERTICAL SECTION OF THE EYE.—(*From Holden's "Anatomy."*)

1. Anterior chamber filled with aqueous humor. 2. Posterior chamber. 3. Canal of Petit. *a.* Hyaloid membrane. *b.* Retina (dotted line). c. Choroid coat (black line). *d.* Sclerotic coat. *e.* Cornea. *f.* Iris. *g.* Ciliary processes. *h.* Canal of Schlemm or Fontana. *i.* Ciliary muscle.

The relationship of the various structures composing the eyeball is shown in Figure 31.

The **dioptric** or **refracting apparatus,** by which the rays of light entering the eye are so manipulated as to produce an image on the retina, consists of the cornea, aqueous humor, crystalline lens, and vitreous humor. A ray of light in passing through each of these media will undergo refraction at their surfaces and ultimately be brought to a focus at the retina. Inasmuch as the two surfaces of the cornea are parallel and its refractive power practically the same as the aqueous humor, the media may be reduced to three—viz.:

1. Cornea and aqueous humor.
2. The lens.
3. The vitreous humor.

The refracting surfaces may also be reduced to three—viz.:

1. Anterior surface of the cornea.
2. Anterior surface of lens.
3. Posterior surface of lens.

The refraction effected by the cornea is very great, owing to the passage of the light from the air into a comparatively dense medium, and is sufficient of itself to bring parallel rays of light to a focus about ten millimeters behind the retina. This would be the condition in an eye in which the lens was congenitally absent. Perfect vision requires, however, that the convergence of the light shall be great enough to allow the image to fall upon the retina. This is

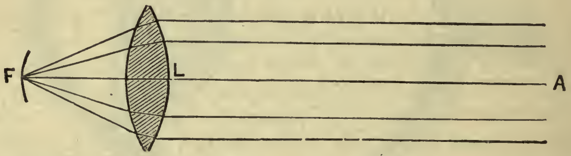

FIG. 32.—DIAGRAM SHOWING THE COURSE OF PARALLEL RAYS OF LIGHT FROM A, IN THEIR PASSAGE THROUGH A BICONVEX LENS, L, IN WHICH THEY ARE SO REFRACTED AS TO BIND TOWARD AND COME IN A FOCUS AT A POINT, F. —(*From Yeo's "Text-book of Physiology."*)

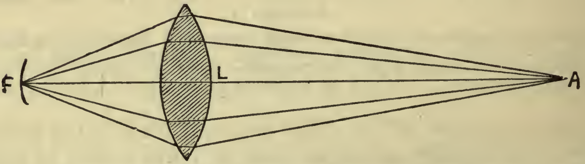

FIG. 33.—DIAGRAM SHOWING THE COURSE OF DIVERGING RAYS WHICH ARE BENT TO A POINT FURTHER FROM THE LENS THAN THE PARALLEL RAYS IN PRECEDING FIGURE.—(*Yeo's "Text-book of Physiology."*)

accomplished by the crystalline lens, a body denser than the cornea and possessing a higher refractive power. The manner in which a biconvex lens focuses both parallel and divergent rays is shown in figures 32 and 33.

The function of the crystalline lens, therefore, is to focus the rays of light with the formation of an image on the retina.

The **retinal image** corresponds in all respects to the object from which the light proceeds. The existence of this image can be demonstrated by removing from the eye of a recently killed animal a circular portion of the sclerotic and choroid posteriorly, and then placing at the proper distance in front of the cornea a lighted candle; an inverted image of the candle will be seen upon the retina. The size of the retinal image depends upon the visual angle, which in turn depends upon the size of the object and its distance from the eye. At a distance of 15.2596 meters the image of an object one meter high would be one millimeter, or a thousand times smaller than the object.

Accommodation.—By accommodation is understood the power which the eye possesses of adjusting itself to vision at different distances. In a normal or emmetropic eye parallel rays of light are brought to a focus on the retina; but divergent rays—that is, rays coming from a near luminous point—will be brought to a focus behind the retina, provided the refractive media remains the same; as a result, vision would be indistinct, from the formation of diffusion circles. It is impossible to see distinctly, therefore, a near and a distant object at the same time. We must alternately direct the vision from one to the other. A normal eye does not require adjusting for parallel rays; but for divergent rays a change in the eye is necessitated; this is termed accommodation. In the accommodation for near vision the lens becomes more convex, particularly on its anterior surface. The increase in convexity augments its refractive power; the greater the degree of divergence of the rays previous to entering the eye, the greater the increase of convexity of the lens and convergence of the rays after passing through it. By this alteration in the shape of the lens we are enabled to focus light rays coming from, and to see distinctly, near as well as distant objects.

Function of the Ciliary Muscle.—Though it is admitted that the change in the convexity of the lens is caused by the contraction of the ciliary muscle and the relaxation of the suspensory ligament, the exact manner in which it does so is not understood. When the eye is in repose, as in distant vision, the suspensory ligament is tense, and the lens possesses that degree of curvature necessary for focusing parallel rays. In the voluntary efforts to accommodate the eye for near vision, the ciliary muscle contracts, the suspensory ligament relaxes, and the lens, inherently elastic, bulges forward and once again focuses the rays upon the retina. It is, therefore, termed the muscle of accommodation, and by its alternate contraction and relaxation the lens is rendered more or less convex, according to the requirements for near and distant vision.

Range of Accommodation.—Parallel rays coming from a luminous point distant not less than 200 feet do not require adjustment; from this point up to infinity no accommodation is required for perfect vision. This is termed the *punctum remotum,* and indicates the distance to which an object may be removed and yet distinctly seen. If the object be brought nearer to the eye than 200 feet, the accommodative power must come into play; the nearer the object, the more energetic must be the contraction of the ciliary muscle and the consequent increase in the convexity of the lens. At a distance of five inches, however, the power of accommodation reaches its maximum; this is termed the *punctum proximum,* and indicates the nearest point at which an object may be seen distinctly. The distance between these two points is the range of accommodation.

Optic Defects.—*Astigmatism* is a condition of the eye which prevents vertical and horizontal lines from being focused at the same time, and is due to a greater curvature of the cornea in one meridian than in another.

Spheric aberration is a condition in which there is an indistinctness of an image from the unequal refraction of the rays of light passing through the circumference and the center of the lens; it is corrected mainly by the iris, which cuts off the marginal rays, and transmits only those passing through the center.

Chromatic aberration is a condition in which the image is surrounded by a colored margin, from the decomposition of the rays of light into their elementary parts.

Myopia, or *shortsightness,* is caused by an abnormal increase in the anteroposterior diameter of the eyeball, or by a hypernormal refracting power of the lens. It is generally due to the first cause;

the lens, being too far removed from the retina, forms the image in front of it, and the perception becomes dim and blurred. *Concave* glasses correct this defect by preventing the rays from converging too soon.

Hypermetropia, or *longsightness,* is caused by a shortening of the anteroposterior diameter or by a subnormal refractive power of the lens; the focus of the rays of light would, therefore, be behind the retina. *Convex* glasses correct this defect by converging the rays of light more anteriorly.

Presbyopia is a loss of the power of accommodation of the eye to near objects, and usually occurs between the ages of forty and sixty; it is remedied by the use of convex glasses.

The Iris.—The iris plays the part of a diaphragm, and by means of its central aperture the pupil regulates the quantity of light entering the interior of the eye; by preventing rays from passing through the margin of the lens it diminishes spheric aberration. The size of the pupil depends upon the relative degree of contraction of the circular and radiating fibers; the variations in size of the pupil from variations in the degree of contraction depend upon different intensities of light. If the light be intense, the circular fibers contract, and diminish the size of the pupil; if the light diminishes in intensity, the circular fibers relax and the pupil enlarges.

Point of Most Distinct Vision.—While all portions of the retina are sensitive to light, their sensibility varies within wide limits. At the macula lutea, and more especially in its most central depression, the fovea, where the retinal elements are reduced practically to the layer of rods and cones, the sensibility reaches its maximum. It is at this point that the image is found when vision is most distinct. The macula and fovea are always in the line of direct vision. From the macula toward the periphery of the retina there is a gradual diminution in sensibility, and a corresponding decline in the distinctness of vision. In those portions of the retina lying outside the macula, the indistinctness of vision depends not only on diminished sensibility, but also upon inaccurate focusing of the rays.

Blind Spot.—Although the optic nerve transmits the impulses excited in the retina by the ethereal vibration, the nerve-fibers themselves are insensitive to light. At the point of entrance of the optic nerve, owing to the absence of the rods and cones, the rays of light make no impression. This is the blind spot. As this spot is not in the line of vision, no dark point is ordinarily observed in the field of vision—the circular space before a fixed eye within which reflections of objects are perceptible.

The *rods* and *cones* are the most sensitive portions of the retina. A ray of light entering the eye passes entirely through the various layers of the retina, and is arrested only upon reaching the pigmentary epithelium in which the rods and cones are embedded. As to the manner in which the objective stimuli—light and color, so called—are transformed into nerve impulses, but little is known. It is probable that the ethereal vibrations are transformed into heat, which excites the rods and cones. These, acting as highly specialized end organs of the optic nerve, start the impulses on their way to the brain, where the seeing process takes place. As to the relative function of the rods and cones, it has been suggested, from the study of the facts of comparative anatomy, that the rods are impressed only by differences in the intensity of light, while the cones, in addition, are impressed by qualitative differences or color.

Accessory Structures.—The muscles which move the eyeball are six in number—the superior and inferior recti, the external and internal recti, the superior and inferior oblique muscles. The four recti muscles, arising from the apex of the orbit pass forward and are inserted into the sides of the sclerotic coat; the *superior* and *inferior* muscles rotate the eye around a *horizontal* axis; the *external* and *internal* rotate it around a *vertical* axis.

The *superior oblique* muscle, having the same origin, passes forward to the inner and upper angle of the orbital cavity, where its tendon passes through a cartilaginous pulley; it is then reflected backward and inserted into the sclerotic just behind the transverse diameter. Its *function* is to rotate the eyeball in such a manner as to direct the pupil *downward* and *outward.*

The *inferior oblique* muscle arises at the inner angle of the orbit, and then passes outward and backward, to be inserted into the sclerotic. Its function is to rotate the eyeball and to direct the pupil *upward* and *outward.*

By the associated action of all these muscles, the eyeball is capable of performing all the varied and complex movements necessary for distinct vision.

The *eyelids,* bordered with short, stiff hairs, shade the eye and protect it from injury. On the posterior surface, just beneath the conjunctiva, are the Meibomian glands, which secrete an oily fluid; this covers the edge of the lids, and prevents the tears from flowing over the cheek.

The *lacrymal glands* are ovoid in shape, and are situated at the upper and outer part of the orbital cavity; they open by from six to eight ducts at the outer portion of the upper lids.

The *tears,* secreted by the lacrymal glands, are distributed over the cornea by the lids during the act of winking, and keep it moist and free from dust. The excess of tears passes into the lacrymal ducts, which begin by two minute orifices, one on each lid, at the inner canthus. They conduct the tears into the nasal duct, and so into the nose.

THE SENSE OF HEARING.

The **ear,** or **organ of hearing,** is lodged within the petrous portion of the temporal bone. It may be, for convenience of description, divided into three portions—viz.:

1. The external ear.
2. The middle ear.
3. The internal ear or labyrinth.

The **external ear** consists of the *pinna,* or *auricle,* and the *external auditory canal.* The *pinna* consists of a thin layer of cartilage, presenting a series of elevations and depressions; it is attached by fibrous tissue to the outer bony edge of the auditory canal; it is covered by a layer of integument continuous with that covering the side of the head. The general shape of the pinna is concave, and presents, a little below the center, a deep depression—the *concha.* The *external auditory canal* extends from the concha inward for a distance of about 1¼ inches. It is directed somewhat forward and upward, passing over a convexity of bone, and then dips downward to its termination; it is composed of both bone and cartilage, and is lined by a reflection of the skin covering the pinna. At the external portion of the canal the skin contains a number of tubular glands,—the *ceruminous glands,*—which in their conformation resemble the perspiratory glands. They secrete the cerumen, or ear-wax.

The **middle ear,** or **tympanum,** is an irregularly shaped cavity hollowed out of the temporal bone and situated between the external ear and the labyrinth. It is narrow from side to side, but relatively long in its vertical and anteroposterior diameters; it is separated from the external auditory canal by a membrane—the *membrana tympani;* from the internal ear it is separated by an osseomembranous partition, which forms a common wall for both cavities. The middle ear communicates posteriorly with the mastoid cells; anteriorly with the nasopharynx, by means of the Eustachian tube. The interior of this cavity is lined by mucous membrane continuous with that lining the pharynx.

The *membrana tympani* is a thin, translucent, nearly circular membrane, measuring about ⅖ of an inch in diameter, placed at the inner termination of the external auditory canal. The membrane is inclosed within a ring of bone, which in the fetal condition can be easily removed, but in the adult condition becomes consolidated with the surrounding bone. The membrana tympani consists primarily of a layer of fibrous tissue, arranged both circularly and radially, and forms the *membrana propria;* externally it is covered by a thin layer of skin continuous with that lining the auditory canal; internally it is covered by a thin mucous membrane. The tympanic membrane is placed obliquely at the bottom of the auditory canal, inclining at an angle of forty-five degrees, being directed from behind and above downward and inward. On its external surface this membrane presents a funnel-shaped depression, the sides of which are somewhat convex.

The Ear Bones.—Running across the tympanic cavity and forming an irregular line of joined levers is a chain of bones which articulate with one another at their extremities. They are known as the malleus, incus, and stapes.

The form and position of these bones are shown in figure 34.

The *malleus* consists of a head, neck, and handle, of which the latter is attached to the inner surface of the membrana tympani; the *incus,* or anvil bone, presents a concave, articular surface, which receives the head of the malleus; the *stapes,* or stirrup bone, articulates externally with the long process of the incus, and internally, by its oval base, with the edges of the foramen ovale.

The **tensor tympani muscle** consists of a fleshy, tapering portion, ½ of an inch in length, which terminates in a slender tendon; it arises from the cartilaginous portion of the Eustachian tube and the adjacent surface of the sphenoid bone. From this origin the muscle passes nearly horizontally backward to the tympanic cavity; just opposite to the fenestra ovalis its tendon bends at a right angle over the processus cochleariformis, and then passes outward across the cavity, to be inserted into the angle of the malleus near the neck.

The **stapedius muscle** emerges from the cavity of a pyramid of bone projecting from the posterior wall of the tympanum; the tendon passes forward, and is inserted into the neck of the stapes bone, posteriorly, near its point of articulation with the incus.

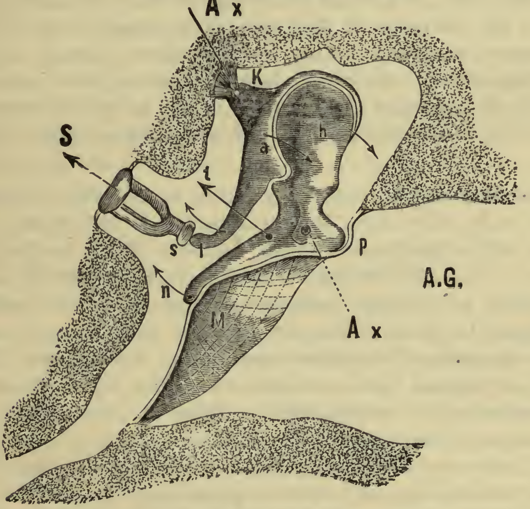

FIG. 34.—TYMPANUM AND AUDITORY OSSICLES (LEFT) MAGNIFIED.

A.G. External meatus. M. Membrana tympani, which is attached to the handle of the malleus, n, and near it the short process, p. h. Head of the malleus. a. Incus; K. its short process, with its ligament; l. long process. s. Sylvian ossicle. S. Stapes. Ax, Ax, is the axis of rotation of the ossicles; it is shown in perspective, and must be imagined to penetrate the plane of the paper. t. Line of traction of the tensor tympani. The other arrows indicate the movement of the ossicles when the tensor contracts.

The laxator tympani muscle, so called, is now generally regarded as being ligamentous in nature, and not muscular.

The **Eustachian tube,** by means of which a free communication is established between the middle ear and the pharynx, is partly bony and partly cartilaginous in structure. It measures about 1½ inches in length; commencing at its opening into the nasopharynx, it passes upward and outward to the spine of the sphenoid bone, at which point it becomes somewhat contracted; the tube then dilates as it passes backward into the middle-ear cavity; it is lined by mucous membrane, which is continued into the middle ear and mastoid cells.

The **function of the ear,** as a whole, is the reception and transmission of aërial vibrations to the terminal organs concealed within the internal ear, and which are connected with the auditory nerve-fibers. The excitation of these end organs caused by the impact of the vibrations arouses in the auditory nerve impulses which are then transmitted to the brain, where the hearing process takes place. In order to appreciate the functions of the individual parts of the ear, a few of the characteristics of sound waves must be kept in mind.

Sound Waves.—All sounds are caused by vibrations in the atmosphere which have been communicated to it by vibrating elastic bodies, such as membranes, strings, rods, etc. These vibrating bodies produce in the air a to-and-fro movement of its particles, resulting in a series of alternate condensations and rarefactions, which are propagated in all directions. A complete oscillation of a particle of air forward and backward constitutes a sound wave. Musical sounds are caused by a succession of regular waves, which follow one another with a certain rapidity. Noises are caused by the impact of a series of irregular waves.

All sound waves possess intensity, pitch, and equality. The *intensity,* or loudness, of a sound depends upon the amplitude of its vibrations or on the extent of its excursion. The *pitch* depends upon the number of vibrations which affect the auditory nerve in a second of time; the pitch of the note C, the first below the leger line of the musical scale, is caused by 256 vibrations a second; the pitch of the same note an octave higher is caused by 512 vibrations a second. If the vibrations are too few a second, they fail to be perceived as a continuous sound; the minimum number of vibrations capable of producing a sound has been fixed at sixteen a second; the highest pitched musical note capable of being heard has been shown to be due to 38,000 vibrations a second. In the ascent of the musical scales there is, therefore, a gradual increase in the number of vibrations and a gradual increase in the pitch of the sounds. Between the two extreme limits lies the range of audibility, which embraces eleven octaves, of which seven are employed in the musical scale.

The *quality* of sound depends upon a combination of the fundamental vibration with certain secondary vibrations of subdivisions of the vibrating body. These so-called over-tones vary in intensity and pitch, and by modifying the form of the primary wave produce that which is termed the quality of sound.

Function of the Pinna and External Auditory Canal.—In those animals possessing movable ears the pinna plays an important part in the collection of sound waves. In man, in whom the capability of moving the pinna has been lost, it is doubtful if it is at all necessary for hearing. Nevertheless an individual with dull hearing may have the perception of sound increased by placing the pinna at an angle of 45 degrees to the side of the head. The *external auditory canal* transmits the sonorous vibrations to the tympanic membrane. Owing to the obliquity of this canal it has been supposed that the waves, concentrated at the concha, undergo a series of reflections on their way to the tympanic membrane, and, owing to the position of this membrane, strike it almost perpendicularly.

Function of the Tympanic Membrane.—The function of the tympanic membrane appears to be the reception of sound vibrations by being thrown by them into reciprocal vibrations which correspond in intensity and amplitude. That this membrane actually reproduces all vibrations within the range of audibility has been experimentally demonstrated. The membrane not being fixed, so far as its tension is concerned, does not possess a fixed fundamental note, like a stationary fixed membrane, and is, therefore, just as well adapted for the reception of one set of vibrations as for another. This is made possible by variations in its tension in accordance with the pitch of the sounds. In the absence of all sound the membrane is in a condition of relaxation; with the advent of sound waves possessing a gradual increase of pitch, as in the ascent of the music scale, the tension of the tympanic membrane is gradually increased until its maximum tension is reached at the upper limit of the range of audibility. By this change in tension certain tones become perceptible and distinct, while others become indistinct and inaudible.

Function of the Tensor Tympani Muscle.—The function of this muscle is, as its name indicates, to increase the tension of the membrane in accordance with the pitch of the sound wave. The tension of this muscle playing over the processus cochleariformis and attached at also a right angle to the handle of the malleus will, when the muscle contracts, pull the handle inward, increase the convexity of the membrane, and at the same time increase its tension; with the relaxation of this muscle, the handle of the malleus passes outward and the tension is diminished. The contractions of the tensor muscle are reflex in character and excited by nerve impulses reaching it through the small petrosal nerve and otic ganglion. The number of nerve stimuli passing to the muscle and determining the degree of contraction will depend upon the pitch of the sound wave and the subsequent excitation of the auditory nerve. The tensor tympani muscle may be regarded as an accommodative apparatus by which the tympanic membrane is so adjusted as to enable it to receive vibrations of varying degrees of pitch.

Function of the Ossicles.—The function of the chain of bones is to transmit the sound wave across the tympanic cavity to the internal ear. The first of these bones, the malleus, being attached to the tympanic membrane, will take up the vibrations much more readily than if no membrane intervened. Owing to the character of the articulations, when the handle of the malleus is drawn inward, the position of the bones is so changed that they form practically a solid rod, and are therefore much better adapted for the transmission of molecular vibrations than if the articulations remained loose. As the stapes bone is somewhat shorter than the malleus, its vibrations are slighter than those of the tympanic membrane, and by this arrangement the amplitude of the vibrations is diminished, but their force increased.

The **function of the stapedius muscle** is, according to Henle, to fix the stapes bone so as to prevent too great a movement from being communicated to it from the incus and transmitted to the perilymph. It may be looked upon, therefore, as a protective muscle.

The **function of the Eustachian tube** is to maintain a free communication between the cavity of the middle ear and the nasopharynx. The pressure of air within and without the ear is thus equalized, and the vibrations of the tympanic membrane are permitted to attain their maximum, one of the conditions essential for the reception of sound waves. The impairment in the acuteness of hearing which is caused by an unequal pressure of the air in the middle ear can be shown—

1. By closing the mouth and nose and forcing air from the lungs through the Eustachian tube into the ear, producing an increase in pressure.
2. By closing the nose and mouth, and making efforts at deglutition, which withdraws the air from the ear and diminishes its pressure.

In both instances the free vibrations of the tympanic membrane are interfered with. The pharyngeal orifice of the Eustachian tube is opened by the action of certain of the muscles of deglutition—viz., the levator palati, the tensor palati, and the palato-pharyngei muscles.

The **internal ear,** or **labyrinth,** is located in the petrous portion of the temporal bone, and consists of an osseous and a membranous portion.

The **osseous labyrinth** is divisible into three parts—viz., the vestibule, the semicircular canals, and the cochlea.

The *vestibule* is a small, triangular cavity, which communicates with the middle ear by the foramen ovule; in the natural condition it is closed by the base of the stapes bone. The filaments of the auditory nerve enter the vestibule through small foramina in the inner wall, at the fovea hemispherica.

The *semicircular canals* are three in number, the superior vertical, the inferior vertical, and the horizontal, each of which opens into the cavity of the vestibule by two openings, with the exception of the two vertical, which at one extremity open by a common orifice.

The *cochlea* forms the anterior part of the internal ear. It is a gradually tapering canal, about 1½ inches in length, which winds spirally around a central axis, the *modiolus,* two and one half times. The interior of the cochlea is partly divided into two passages by a thin plate of bone, the *lamina osseous spiralis,* which projects from the central axis two thirds of the way across the canal. These passages are termed the *scala vestibuli* and the *scala tympani,* from their communication with the vestibule and tympanum The scala tympani communicates with the middle ear through the *foramen rotundum,* which, in the natural condition, is closed by the second membrana tympani; superiorly they are united by an opening, the helicotrema.

The whole interior of the labyrinth, the vestibule, the semicircular canals, and the scala of the cochlea, contains a clear, limpid fluid, the *perilymph* secreted by the periosteum lining the osseous walls.

The **membranous labyrinth** corresponds to the osseous labyrinth with respect to form, though it is somewhat smaller in size.

The *vestibular* portion consists of two small sacs, the *utricle* and the *saccule.*

The *semicircular canals* communicate with the *utricle* in the same manner as the bony canals communicate with the vestibule. The *saccule* communicates with the membranous cochlea by the canalis reuniens. In the interior of the utricle and saccule, at the entrance of the auditory nerve, are small masses of carbonate of lime crystals, constituting the *otoliths.* Their function is unknown.

The *membranous cochlea* is a closed tube, commencing by a blind extremity at the first turn of the cochlea, and terminating at its apex by a blind extremity also. It is situated between the edge of the *osseous lamina spiralis* and the outer wall of the bony cochlea, and follows it in its turns around the modiolus.

A transverse section of the cochlea shows that it is divided into two portions by the osseous lamina and the basilar membrane:

1. The *scala vestibuli,* bounded by the periosteum and membrane of Reissner.
2. The *scala tympania,* occupying the inferior portion, and bounded above by the septum, composed of the osseous lamina and the membrana basilaris.

The *true membranous canal* is situated between the membrane of Reissner and the basilar membrane. It is triangular in shape, but is partly divided into a triangular portion and a quadrilateral portion by the *tectorial* membrane.

The *organ of Corti* is situated in the quadrilateral portion of the canal, and consists of pillars of rods of the consistence of cartilage. They are arranged in two rows—the one internal, the other external; these rods rest upon the basilar membrane; their bases are separated from one another, but their upper extremities are united, forming an arcade. In the internal row it is estimated there are about 3,500 and in the external row about 5,200 of these rods.

On the inner side of the internal row is a single layer of elongated hair-cells; on the outer surface of the external row are three such layers of hair-cells. Nothing definite is known as to their function.

The *endolymph* occupies the interior of the utricle, saccule, and membranous canals, and bathes the structures in the interior of the membranous cochlea throughout its entire extent.

The **auditory nerve** at the bottom of the internal auditory meatus divides into—

1. A vestibular branch, which is distributed to the utricle and to the semicircular canals.
2. A cochlear branch, which passes into the central axis at its base and ascends to its apex; as it ascends, fibers are given off, which pass between the plates of the osseous lamina, to be ultimately connected with the organ of Corti.

The *function* of the semicircular canals appears to be to assist in maintaining the equilibrium of the body; destruction of the vertical canal is followed by an oscillation of the head upward and downward; destruction of the horizontal canal is followed by oscillations from left to right. When the canals are injured on both sides, the animal loses the power of maintaining equilibrium upon making muscular movements.

Function of the Cochlea.—It is regarded as possessing the power of appreciating the quality of pitch and the shades of different musical tones. The elements of the organ of Corti are analogous, in some respects, to a musical instrument, and are supposed, by Helmholtz, to be tuned so as to vibrate in unison with the different tones conveyed to the internal ear.

Summary.—The waves of sound are gathered together by the pinna and external auditory meatus, and conveyed to the membrana tympani. This membrane, made tense or lax by the action of the tensor tympani and laxator tympani muscles, is enabled to receive sound waves of either high or low pitch. The vibrations are conducted across the middle ear by a chain of bones to the foramen ovale, and by the column of air of the tympanum to the foramen rotundum, which is closed by the second membrana tympani, the pressure of the air in the tympanum being regulated by the Eustachian tube.

The internal ear finally receives the vibrations, which excite vibrations successively in the perilymph, the walls of the membranous labyrinth, the endolymph, and, lastly, the terminal filaments of the auditory nerve, by which they are conveyed to the brain.

VOICE AND SPEECH.

The **larynx** is the organ of voice. Speech is a modification of voice, and is produced by the teeth and the muscles of the lips and tongue, coördinated in their action by stimuli derived from the cerebrum.

The **structures** entering into the formation of the larynx are mainly the *thyroid, cricoid,* and *arytenoid* cartilages; they are so situated and united by means of ligaments and muscles as to form a firm cartilaginous box. The larynx is covered externally by fibrous tissue, and lined internally with mucous membrane.

The **vocal cords** are four ligamentous bands, running anteroposteriorly across the upper portion of the larynx, and are divided into the *two superior* or *false* vocal cords, and the *two inferior* or *true* vocal cords; they are attached anteriorly to the receding angle of the thyroid cartilages, and posteriorly to the anterior part of the base of the arytenoid cartilages. The space between the true vocal cords is the *rima glottidis.*

The **muscles** which have a direct action upon the movements of the vocal cords are nine in number, and take their names from their points of origin and insertion—viz., the two *crico-thyroid,* two *thyro-arytenoid,* two *posterior crico-arytenoid,* two *lateral crico-arytenoid,* and one *arytenoid* muscles.

The *crico-thyroid* muscles, by their contraction, render the vocal cords *more tense* by drawing down the anterior portion of the thyroid cartilage and approximating it to the cricoid, and at the same time tilting the posterior portion of the cricoid and arytenoid cartilages backward.

The *thyro-arytenoid,* by their contraction, *relax* the vocal cords by drawing the arytenoid cartilage forward and the thyroid backward.

The *posterior crico-arytenoid* muscles, by their contraction, rotate the arytenoid cartilages outward and thus separate the vocal cords and enlarge the aperture of the glottis. They principally aid the respiratory movements during inspiration.

The *lateral crico-arytenoid* muscles are antagonistic to the former, and by their contraction rotate the arytenoid cartilages so as to approximate the vocal cords and constrict the glottis.

The *arytenoid* muscle assists in the closure of the aperture of the glottis.

The *inferior laryngeal* nerve animates all the muscles of the larynx, with the exception of the crico-thyroid.

Movements of the Vocal Cords.—During respiration the movement of the vocal cords differ from those occurring during the production of voice.

At each *inspiration* the true vocal cords are widely separated, and the aperture of the glottis is enlarged by the action of the crico-arytenoid muscles, which rotate outward the anterior angle of the base of the arytenoid cartilages; at each *expiration* the larynx becomes passive; the elasticity of the vocal cords returns them to their original position, and the air is forced out by the elasticity of the lungs and the walls of the thorax.

Phonation.—As soon as phonation is about to be accomplished, a marked change in the glottis is noticed with the aid of the laryngoscope. The true vocal cords suddenly become approximated and are made parallel, giving to the glottis the appearance of a narrow slit, the edges of which are capable of vibrating accurately and rapidly; at the same time their tension is much increased.

With the vocal cords thus prepared, the expiratory muscles force the column of air into the lungs and trachea through the glottis, throwing the edges of the cords into vibration.

The *pitch* of sounds depends upon the extent to which the vocal cords are made tense and the length of the aperture through which the air passes. In the production of sounds of a high pitch, the tension of the vocal cords becomes very marked and the glottis diminished in length. When sounds having a low pitch are emitted from the larynx, the vocal cords are less tense and their vibrations are large and loose.

The *quality* of voice depends upon the length, size, and thickness of the cords, and upon the size, form, and construction of the trachea, the larynx, and the resonant cavities of the pharynx, nose, and mouth.

The *compass* of the voice comprehends from two to three octaves. The range is different in the two sexes, the lowest note of the male being about one octave lower than the lowest note of the female; while the highest note of the male is an octave less than the highest note of the female.

The *varieties* of voice—*e. g.,* bass, baritone, tenor, contralto, mezzo-soprano, and soprana—are due to the length of the vocal cords, being longer when the voice has a low pitch, and shorter when it has a high pitch.

Speech is the faculty of expressing ideas by means of combinations of sounds, in obedience to the dictates of the cerebrum.

Articulate sounds may be divided into *vowels* and *consonants.* The *vowel sounds, a, e, i, o, u,* are produced in the larynx by the vocal cords. The *consonant sounds* are produced in the air-passages above the larynx by an interruption of the current of air by the lips, tongue, and teeth; the consonants may be divided into:

1. Mutes, *b, d, k, p, t, c, g.*
2. Dentals, *d, j, s, t, z.*
3. Nasals, *m, n, ng.*
4. Labials, *b, p, f, v, m.*
5. Gutturals, *k, g, c,* and *g* hard.
6. Liquids, *l, m, n, r.*

EMBRYOLOGY.

Reproduction is the function by which the species is preserved; it is accomplished by the organs of generation in the two sexes. Embryology is the science which investigates the successive stages in the development of the embryo.

GENERATIVE ORGANS OF THE FEMALE.

The **generative organs of the female** consist of the ovaries, Fallopian tubes, uterus, and vagina.

The **ovaries** are two small, ovoid, flattened bodies, measuring 1½ inches in length and ¾ of an inch in width; they are situated in the cavity of the pelvis, and are imbedded in the posterior layer of the broad ligament; attached to the uterus by a round ligament, and to the extremities of the Fallopian tubes by the fimbriæ. The ovary consists of an external membrane of fibrous tissue, the *cortical* portion, in which are embedded the *Graafian vesicles,* and an internal portion, the *stroma,* containing blood-vessels.

The **Graafian vesicles** are exceedingly numerous, but are situated only in the cortical portion. Although the ovary contains the vesicles from the period of birth, it is only at puberty that they attain their full development. From this time onward to the catamenial period there is a constant growth and maturation of the Graafian vesicles. They consist of an external investment, composed of fibrous tissues and blood-vessels, in the interior of which is a layer of cells forming the *membrana granulosa;* at its lower portion there is an accumulation of cells, the *proligerous disc,* in which the *ovum* is contained. The cavity of the vesicle contains a slightly yellowish alkaline, albuminous fluid.

The **ovum** is a globular body, measuring about $\frac{1}{125}$ of an inch in diameter; it consists of an external investing membrane, the *vitelline membrane;* a central granular substance, the *vitellus,* or *yolk;* a nucleus, the *germinal vesicle,* in the interior of which is imbedded the nucleolus, or *germinal spot.*

The **Fallopian tubes** are about four inches in length, and extend outward from the upper angles of the uterus, between the folds of the broad ligaments, and terminate in a fringed extremity which is attached by one of the fringes to the ovary. They consist of three coats:

1. The external, or peritoneal.
2. Middle, or muscular, the fibers of which are arranged in a circular or longitudinal direction.
3. Internal, or mucous, covered with ciliated epithelial cells, which are always waving from the ovary toward the uterus.

The **uterus** is pyriform in shape, and may be divided into a body and neck; it measures about three inches in length and two inches in breadth in the unimpregnated state. At the lower extremity of the neck is the os externum; at the junction of the neck with the body is a constriction, the os internum. The cavity of the uterus is triangular in shape, the walls of the triangle being almost in contact.

The walls of the uterus are made up of several layers of non-striated muscle-fibers, covered externally by peritoneum, and lined internally by mucous membrane, containing numerous tubular glands, and covered by ciliated epithelial cells.

The **vagina** is a membranous canal, from five to six inches in length, situated between the rectum and bladder. It extends obliquely upward from the surface, almost to the brim of the pelvis, and embraces at its upper extremity the neck of the uterus.

Discharge of the Ovum.—As the Graafian vesicle matures it increases in size, from an augmentation of its liquid contents, and approaches the surface of the ovary, where it forms a projection, measuring from ¼ to ½ of an inch. The maturation of the vesicle occurs periodically, about every twenty-eight days, and is attended by the phenomena of menstruation. During this period of active congestion of the reproductive organs the Graafian vesicle ruptures, the ovum and liquid contents escape, and are caught by the fimbriated extremity of the Fallopian tube, which has adapted itself to the posterior surface of the ovary. The passage of the ovum through the Fallopian tube into the uterus occupies from ten to fourteen days, and is accomplished by muscular contraction and by the action of the ciliated epithelium.

Menstruation is a periodic discharge of blood from the mucous membrane of the uterus, due to a fatty degeneration of the small blood-vessels. Under the pressure of an increased amount of blood in the reproductive organs, attending the process of ovulation, the blood-vessels rupture, and a hemorrhage takes place into the uterine cavity; thence it passes into the vagina. Menstruation lasts from five to six days, and the amount of blood discharged averages about five ounces.

Corpus Luteum.—For some time previous to the rupture of a Graafian vesicle it increases in size and becomes vascular; its walls become thickened from the deposition of a reddish-yellow, glutinous substance, a product of cell growth from the proper coat of the follicle and the membrana granulosa. After the ovum escapes there is usually a small effusion of blood into the cavity of the follicle, which soon coagulates, loses its coloring-matter, and acquires the characteristics of fibrin, but it takes no part in the formation of the corpus luteum. The walls of the follicle become convoluted and vascular, and undergo hypertrophy, until they occupy the whole of the follicular cavity. At its period of fullest development the corpus luteum measures ¾ of an inch in length and ½ of an inch in depth. In a few weeks the mass loses its red color and becomes yellow, constituting the *corpus luteum,* or *yellow body.* It then begins to retract and becomes pale; and at the end of two months nothing remains but a small cicatrix upon the surface of the ovary. Such are the changes in the follicle if the ovum has not been impregnated.

The corpus luteum, after impregnation has taken place, undergoes a much slower development, becomes larger, and continues during the entire period of gestation. The difference between the corpus luteum of the unimpregnated and pregnant condition is expressed in the following table by Dalton:

	Corpus Luteum of Menstruation.	*Corpus Luteum of Pregnancy.*
At the end of three weeks.	Three quarters of an inch in diameter; central clot reddish; convoluted wall pale.	
One month.	Smaller; convoluted wall bright yellow; clot still reddish.	Larger; convoluted wall bright yellow; clot still reddish.
Two months.	Reduced to the condition of an insignificant cicatrix.	Seven eighths of an inch in diameter; convoluted wall bright yellow; clot perfectly decolorized.

Four months.	Absent or unnoticeable.	Seven eighths of an inch in diameter; clot pale and fibrinous; convoluted wall dull yellow.
Six months.	Absent.	Still as large as at the end of second month; clot fibrinous; convoluted wall paler.
Nine months.	Absent.	Half an inch in diameter; central clot converted into a radiating cicatrix; external wall tolerably thick and convoluted, but without any bright yellow color.

GENERATIVE ORGANS OF THE MALE.

The **generative organs of the male** consist of the testicles, vasa deferentia, vesiculæ seminales, and penis.

The **testicles,** the essential organs of reproduction in the male, are two oblong glands, about 1½ inches in length, compressed from side to side, and situated in the cavity of the scrotum.

The proper coat of the testicle, the *tunica albuginea,* is a white, fibrous structure, about $\frac{1}{25}$ of an inch in thickness; after enveloping the testicle, it is reflected into its interior at the posterior border, and forms a vertical process, the *mediastinum testis,* from which septa are given off, dividing the testicle into lobules.

The substance of the testicle is made up of the *seminiferous tubules,* which exist to the number of 840; they are exceedingly convoluted, and when unravelled are about thirty inches in length. As they pass toward the apices of the lobules, they become less convoluted, and terminate in from twenty to thirty straight ducts, the *vasa recta,* which pass upward through the *mediastinum* and constitute the *rete testis.* At the upper part of the mediastinum the lobules unite to form from nine to thirty small ducts, the *vasa efferentia,* which become convoluted and form the *globus major* of the *epididymis;* the continuation of the tubes downward behind the testicle and a second convolution constitutes the *body* and *globus minor.*

The seminal tubule consists of a basement membrane lined by granular nucleated epithelium.

The **vas deferens,** the excretory duct of the testicle, is about two feet in length, and may be traced upward from the epididymis to the under surface of the base of the bladder, where it unites with the duct of the vesicula seminalis to form the ejaculatory duct.

The **vesiculæ seminales** are two lobulated, pyriform bodies about two inches in length, situated on the inner surface of the bladder. They have an external fibrous coat, a middle muscular coat, and an internal mucous coat, covered by epithelium, which secretes a mucous fluid. The vesiculæ seminales serve as reservoirs, in which the seminal fluid is temporarily stored up.

The **ejaculatory duct,** about ¾ of an inch in length, opens into the urethra, and is formed by the union of the vasa deferentia and the ducts of the vesiculæ seminales.

The **prostate gland** surrounds the posterior extremity of the urethra, and opens into it by from twenty to thirty openings, the orifices of the *prostatic tubules.* The gland secretes a fluid which forms part of the semen and assists in maintaining the vitality of the spermatozoa.

Semen is a complex fluid, made up of the secretions from the testicles, the vesiculæ seminales, the prostatic and urethral glands. It is grayish-white in color, mucilaginous in consistence, of a characteristic odor, and somewhat heavier than water. From half a dram to a dram is ejaculated at each orgasm.

The **spermatozoa** are peculiar anatomic elements, developed within the seminal tubules, and possess the power of spontaneous movement. The spermatozoa consist of a conoid head and a long, filamentous tail, which is in continuous and active motion; so long as they remain in the vas deferens they are quiescent, but when free to move in the fluid of the vesiculæ seminales, they become very active.

Origin.—The spermatozoa appear at the age of puberty, and are then constantly formed until an advanced age. They are developed from the nuclei of large, round cells contained in the anterior of the seminal tubules, as many as fifteen to twenty developing in a single cell.

When the spermatozoa are introduced into the vagina, they pass readily into the uterus and through the Fallopian tubes toward the ovaries, where they remain and retain their vitality for a period of from eight to ten days.

Fecundation is the union of the spermatozoa with the ovum during its passage toward the uterus, and usually takes place in the Fallopian tube, just outside the womb. After floating around the ovum in an active manner, they penetrate the vitelline membrane, pass into the interior of the vitellus, where they lose their vitality, and, along with the germinal vesicle, entirely disappear.

DEVELOPMENT OF ACCESSORY STRUCTURES.

Segmentation of the Vitellus.—After the disappearance of the spermatozoa and the germinal vesicle there remains a transparent, granular, albuminous substance, in the center of which a new nucleus soon appears; this constitutes the *parent cells,* and is the first stage in the development of the new being.

Following this, the vitellus undergoes *segmentation;* a constriction appears on the opposite side of the vitellus, which gradually deepens, until the yolk is divided into two segments, each of which has a distinct nucleus and nucleolus; these two segments undergo a further division into four, the four into eight, the eight into others, and so on, until the entire vitellus is divided into a great number of cells, each of which contains a nucleus and a nucleolus.

The peripheral cells of this "mulberry mass" then arrange themselves so as to form a membrane, and, as they are subjected to mutual pressure, assume a polyhedral shape, which gives to the membrane a mosaic appearance. The central part of the vitellus becomes filled with a clear fluid. A second membrane shortly appears within the first, and the two together constitute the external and internal blastodermic membranes.

Blastodermic Membranes.—The embryo, at this period, consists of three layers—viz., the external and the internal blastodermic membranes and a middle membrane formed by a genesis of cells from their internal surfaces. These layers are known as the epiblast, mesoblast, and hypoblast.

The *epiblast* gives rise to the central nervous system, the epidermis of the skin and its appendages, and the primitive kidneys.

The *mesoblast* gives rise to the dermis, muscles, bones, nerves, blood-vessels, sympathetic nervous system, connective tissue, the urinary and reproductive apparatus, and the walls of the alimentary canal.

The *hypoblast* gives rise to the epithelial lining of the alimentary canal and its glandular appendages, the liver and pancreas, and the epithelium of the respiratory tract.

Germinal Area.—At about this period there is an accumulation of cells at a certain spot upon the surface of the blastodermic membranes, which marks the position of the future embryo. This spot, at first circular, soon becomes elongated, and forms the *primitive trace,* around which is a clear space, the *area pellucida,* which is itself surrounded by a darker region, the *area opaca.*

The primitive trace soon disappears, and the area pellucida becomes guitar-shaped; a new groove, the *medullary groove,* is now formed, which develops from before backward, and becomes the neural canal.

Dorsal Laminæ.—As development advances, the true medullary groove deepens, and there arise two longitudinal elevations of the epiblast,—the *dorsal laminæ,* one on either side of the groove,—which grow up, arch over, and unite so as to form a closed tube, the primitive central nervous system.

The **chorda dorsalis** is a cylindric rod running almost throughout the entire length of the embryo. It is formed by an aggregation of mesoblastic cells, and is situated immediately beneath the medullary groove.

Primitive Vertebræ.—On either side of the neural canal the cells of the mesoblast undergo a longitudinal thickening, which develops and extends around the neural canal and the chorda dorsalis, and forms the arches and bodies of the vertebræ. They become divided transversely into four-sided segments.

The *mesoblast* now separates into two layers: the external, joining with the epiblast, forms the *somatopleura;* the internal, joining with the hypoblast, forms the *splanchnopleura;* the space between them constitutes the *pleuro-peritoneal* cavity.

Visceral Laminæ.—The walls of the pleuro-peritoneal cavity are formed by a downward prolongation of the somatopleura (the *visceral laminæ*), which, as they extend around in front, pinch off a portion of the yolk-sac (formed by the splanchnopleura), which becomes the primitive alimentary canal; the lower portion, remaining outside of the body cavity, forms the *umbilical vesicle,* which after a time disappears.

Formation of Fetal Membranes.—The amnion appears shortly after the embryo begins to develop, and is formed by folds of the epiblast and external layer of the mesoblast, rising up in front and behind and on each side; these amniotic folds gradually extend over the back of the embryo to a certain point, where they coalesce and inclose a cavity—the amniotic cavity. The membranous partition between the folds disappears, and the outer layer recedes and becomes blended with the vitelline membrane, constituting the *chorion* —the external covering of the embryo.

The Allantois.—As the amnion develops, there grows out from the posterior portion of the alimentary canal a pouch, or diverticulum (the *allantois*), which carries blood-vessels derived from the intestinal circulation. As it gradually enlarges it becomes more vascular, and inserts itself between the two layers of the amnion, coming into intimate contact with the external layer. Finally, from increased growth, it completely surrounds the embryo, and its edges become fused together.

In the bird the allantois is a respiratory organ, absorbing oxygen and exhaling carbonic acid; it also absorbs nutritive matter from the interior of the egg.

Amniotic Fluid.—The amnion, when first formed, is in close contact with the surface of the ovum; but it soon enlarges, and becomes filled with a clear, transparent fluid, containing albumin, glucose, fatty matters, urea, and inorganic salts. It increases in amount up to the latter period of gestation, when it amounts to about two pints. In the space between the amnion and allantois is a gelatinous material, which is encroached upon and finally disappears as the amnion and allantois come in contact, at about the fifth month.

The **chorion,** the external investment of the embryo, is formed by a fusion of the original vitelline membrane, the external layer of the amnion, and the allantois. The external surface now becomes covered with villous processes, which increase in number and size by the continual budding and growth of club-shaped processes from the main stem, and give to the chorion a shaggy appearance. They consist of a homogeneous granular matter, and are penetrated by branches of the blood-vessels derived from the aorta.

The presence of villous processes in the uterine cavity is proof positive of the previous existence of a fetus. They are characteristic of the chorion, and are found under no other circumstances.

At about the end of the second month the villosities begin to atrophy and disappear from the surface of the chorion, with the exception of those situated at the points of entrance of the fetal blood-vessels, which occupy about one third of its surface, where they continue to grow longer, become more vascular, and ultimately assist in the formation of the placenta; the remaining two thirds of the surface loses its villi and blood-vessels and becomes a simple membrane.

The **umbilical cord** connects the fetus with that portion of the chorion which forms the fetal side of the placenta. It is a process of the allantois, and contains two arteries and a vein, which have a more or less spiral direction. It appears at the end of the first month, and gradually increases in length until, at the end of gestation, it measures about twenty inches. The cord is also surrounded by a process of the amnion.

Development of the Decidual Membrane.—The interior of the uterus is lined by a thin, delicate mucous membrane, in which are embedded immense numbers of tubules, terminating in blind extremities—the *uterine tubules.* At each period of menstruation the mucous membrane becomes thickened and vascular, which condition, however, disappears after the usual menstrual discharge. When the ovum becomes fecundated, the mucous membrane takes on an increased growth, becomes more hypertrophied and vascular, sends up little processes or elevations from its surface, and constitutes the *decidua vera.*

As the ovum passes from the Fallopian tube into the interior of the uterus, the primitive vitelline membrane, covered with villosities, becomes entangled with the processes of the mucous membrane. A portion of the decidua vera then grows up on all sides and incloses the ovum, forming the decidua reflexa, while the villous processes of the chorion insert themselves into the uterine tubules and in the mucous membrane between them.

As development advances, the decidua reflexa increases in size, and at about the end of the fourth month comes in contact with the decidua vera, with which it is ultimately fused.

The Placenta.—Of all the embryonic structures, the placenta is the most important. It is formed in the third month, and then increases in size until the seventh month, when a retrogressive metamorphosis takes place until its separation during labor, at which time it is of an oval or rounded shape, and measures from seven to nine inches in length, six to eight inches in breadth, and weighs from fifteen to twenty ounces. It is most frequently situated at the upper and posterior part of the inner surface of the uterus.

The placenta consists of two portions, a fetal and a maternal.

The *fetal portion* is formed by the villi of the chorion, which, by developing, rapidly increase in size and number. They become branched and penetrate the uterine tubules, which enlarge and receive their many ramifications. The capillary blood-vessels in the anterior of the villi also enlarge and freely anastomose with one another.

The *maternal portion* is formed from that part of the hypertrophied and vascular decidual membrane between the ovum and the uterus, the *decidua serotina*. As the placenta increases in size, the maternal blood-vessels around the tubules become more and more numerous, and gradually fuse together, forming great lakes, which constitute sinuses in the walls of the uterus.

As the terminal period of gestation approaches, the villi extend deeper into the decidua, while the sinuses in the maternal portion become larger and extend further into the chorion. Finally, from excessive development of the blood-vessels, the structures between them disappear, and as their walls come in contact they fuse together, so that, ultimately, the maternal and fetal blood are separated only by a thin layer of a homogeneous substance. When fully formed, the placenta consists principally of blood-vessels interlacing in every direction. The blood of the mother passes from the uterine vessels into the lake surrounding the villi; the blood from the fetus flows from the umbilical arteries into the interior of the villi; but there is not at any time an intermingling of blood, the two being separated by a delicate membrane formed by a fusion of the walls of the blood-vessels and the walls of the villi and uterine sinuses.

The function of the placenta, besides nutrition, is that of a *respiratory organ,* permitting the oxygen of the maternal blood to pass by osmosis through the delicate placental membrane into the blood of the fetus; at the same time permitting the carbonic acid and other waste products, the result of nutritive changes in the fetus, to pass into the maternal blood, and so to be carried to the various eliminating organs.

Through the placenta also passes all the nutritious materials of the maternal blood which are essential to the development of the embryo.

At about the middle of gestation there develops beneath the decidual membrane a new mucous membrane, destined to perform the functions of the old when it is extruded from the womb, along with the other embryonic structures, during parturition.

DEVELOPMENT OF THE EMBRYO.

Nervous System.—The cerebro-spinal axis is formed within the medullary canal by the development of cells from its inner surfaces, which, as they increase, fill up the canal, and there remains only the central canal of the cord. The external surface gives rise to the dura mater and pia mater. The neural canal thus formed is a tubular membrane; it terminates posteriorly in an oval dilatation, and anteriorly in a bulbous extremity, which soon becomes partially contracted, and forms the anterior, middle, and posterior cerebral vesicles, from which are ultimately developed the cerebrum, the corpora quadrigemina, and the medulla oblongata, respectively.

The *anterior vesicle* soon subdivides into two secondary vesicles, the larger of which becomes the hemispheres, the smaller the optic thalami; the *posterior vesicle* also divides into two, the anterior becoming the cerebellum, the posterior the pons Varolii and medulla oblongata.

About the seventh week the straight chain of cerebral vesicles becomes curved from behind forward and forms three prominent angles. As development advances, the relative size of the encephalic masses changes. The cerebrum, developing more rapidly than the posterior portion of the brain, soon grows backward and arches over the optic thalami and the tubercula quadrigemina; the cerebellum overlaps the medulla oblongata.

The surface of the cerebral hemispheres is at first smooth, but at about the fourth month begins to be marked by the future fissures and convolutions.

The **eye** is formed by a little bud projecting from the side of the anterior vesicle. It is at first hollow, but becomes lined with nervous matter, forming the *optic nerve* and *retina;* the remainder of the cavity is occupied by the *vitreous body.* The anterior portion of the pouch becomes invaginated and receives the *crystalline lens,* which is a product of the epiblast, as is also the cornea. The *iris* appears as a circular membrane without a central aperture, about the seventh week; the eyelids are formed between the second and third months.

The **internal ear** is developed from the *auditory vesicle,* budding from the third cerebral vesicle; the membranous vestibule appears first, and from it diverticula are given off, which become the semicircular canals and the cochlea.

The cavity of the tympanum, the Eustachian tube, and the external auditory canal are the remains of the first branchial cleft, the cavity of this cleft being subdivided into the tympanum and external auditory meatus by the membrana tympani.

The Skeleton.—The chorda dorsalis, the primitive part of the vertebral column, is a cartilaginous rod situated beneath the medullary groove. It is a temporary structure, and disappears as the true bony vertebræ develop. On either side are the quadrate masses of the mesoblast, the primitive vertebræ, which send processes upward and around the medullary groove, and downward and around the chorda dorsalis, forming in these situations the arches and bodies of the future vertebræ.

More externally the outer layers of the mesoblast and epiblast arch downward and forward, forming the *ventral* laminæ, in which develop the *muscles* and *bones* of the abdominal walls.

The *true cranium* is an anterior development of the vertebral column, and consists of the occipital, parietal, and frontal segments, which correspond to the three cerebral vesicles. The *base of the cranium* consists, at this period, of a cartilaginous rod on either side of the anterior extremity of the chorda dorsalis, in which three centers of ossification appear, the *basi-occipital,* the *basisphenoid,* and the *presphenoid.* They ultimately develop into the basilar process of the occipital bone and the body of the sphenoid.

The *entire skeleton* is at first either membranous or cartilaginous. At the beginning of the second month centers of ossification appear in the jaws and clavicle; as development advances the ossific points in all the future bones extend, until ossification is completed.

The *limbs develop* from four little buds projecting from the sides of the embryo, which, as they increase in length, separate into the thigh, leg, and foot, and the arm, forearm, and hand; the extremities of the limbs undergo subdivision, to form the fingers and toes.

Face and Visceral Arches.—In the facial and cervical regions the visceral laminæ send up three processes, the *visceral arches,* separated by clefts, the *visceral clefts.*

The *first,* or the *mandibular arches,* unite in the median line to form the lower jaw, and superiorly form the malleus. A process jutting from its base grows forward, unites with the frontonasal process growing from above, and forms the upper jaw. When the superior maxillary processes fail to unite there results the *cleft-palate* deformity; if the integument also fails to unite there results the *hare-lip* deformity. The space above the mandibular arch becomes the mouth.

The *second arch* develops the incus and stapes bones, the styloid process and ligament, and the lesser cornu of the hyoid bone. The cleft between the first and second arches partially closes up, but there remains an opening at the side, which becomes the Eustachian tube, tympanic cavity, and external auditory meatus.

The *third arch* develops the body and greater cornu of the hyoid bone.

Alimentary Canal and Its Appendages.—The alimentary canal is formed by a pinching-off of the yolk-sac by the visceral plates as they grow downward and forward. It consists of three distinct portions —the fore gut, the hind gut, and the central part, which communicates for some time with the yolk-sac. It is at first a straight tube, closed at both extremities, lying just beneath the vertebral column. The canal gradually increases in length and becomes more or less convoluted; at its anterior portion two pouches appear, which become the cardiac and pyloric extremities of the stomach. At about the seventh week the inferior extremity of the intestine is brought into communication with the exterior by an opening, the anus. Anteriorly the mouth and pharynx are formed by an involution of epiblast, which deepens until it communicates with the fore gut.

The *liver* appears as a slight protrusion from the sides of the alimentary canal, about the end of the first month; it grows very rapidly, attains a large size, and almost fills up the abdominal cavity. The hepatic cells are derived from the intestinal epithelium, the vessels and connective tissue from the mesoblast.

The *pancreas* is formed by the hypoblastic membrane. It originates in two small ducts budding from the duodenum, which divide and subdivide, and develop the glandular structure.

The *lungs* are developed from the anterior part of the esophagus. At first a small bud appears, which, as it lengthens, divides into two branches; second and tertiary processes are given off from these, which form the bronchial tubes and air-cells. The lungs originally extended into the abdominal cavity, but became confined to the thorax by the development of the diaphragm.

The *bladder* is formed by a dilatation of that portion of the allantois remaining within the abdominal cavity. It is at first pear-shaped and communicates with the intestine, but later becomes separated and opens exteriorly by the urethra. It is attached to the abdominal walls by a rounded cord—the urachus, the remains of a portion of the allantois.

Genito-urinary Apparatus.—The *Wolffian bodies* appear about the thirteenth day, as long, hollow tubes running along each side of the primitive vertebral column. They are temporary structures, and are sometimes called the primordial kidneys. The Wolffian bodies consist of tubules which run transversely and are lined with epithelium; internally they become invaginated to receive tufts of blood-vessels; externally they open into a common excretory duct, the *duct* of the *Wolffian body,* which unites with the duct of the opposite body and empties into the intestinal canal at a point opposite the allantois. On the outer side of the Wolffian body there appears another duct, the duct of Müller, which also opens into the intestine.

Behind the Wolffian bodies are developed the structures which become either the ovaries or testicles. In the development of the female the Wolffian bodies and their ducts disappear; the extremities of the Müllerian ducts dilate and form the fimbriated extremity of the Fallopian tubes, while the lower portions coalesce to form the body of the uterus and vagina, which now separate themselves from the intestine.

In the development of the male the Müllerian ducts atrophy, and the ducts of the Wolffian body ultimately form the epididymis and vas deferens. About the seventh month the testicles begin to descend, and by the ninth month have passed through the abdominal ring into the scrotum.

The *kidneys* are developed out of the Wolffian bodies. They consist of little pyramidal lobules, composed of tubules which open at the apex into the pelvis. As they pass outward they become convoluted and cup-shaped at their extremities, receive a tuft of blood-vessels, and form the Malpighian bodies.

The *ureters* are developed from the kidneys and pass downward to be connected with the bladder.

The **circulatory apparatus** assumes three forms at different periods of life, all having reference to the manner in which the embryo receives nutritive matter and is freed of waste products.

The *vitelline circulation* appears first and absorbs nutritive material from the vitellus. It is formed by blood-vessels which emerge from the body and ramify over a portion of the vitelline membrane, constituting the *area vasculosa.* The heart, lying in the median line, gives off two arches, which unite to form the abdominal aorta, from which two large arteries are given off, passing into the vascular area; the venous blood is returned by veins which enter the heart. These vessels are known as the *omphalo-mesenteric arteries and veins.* The vitelline circulation is of short duration in mammals, as the supply of nutritive matter in the vitellus soon becomes exhausted.

The *placental circulation* becomes established when the blood-vessels in the allantois enter the villous processes of the chorion and come into close relationship with the maternal blood-vessels. The circulation lasts during the whole of intra-uterine life, but gives way at birth to the adult circulation, the change being made possible by the development of the circulatory apparatus.

The *heart* appears as a mass of cells coming off from the anterior portion of the intestine; its central part liquefies, and pulsations soon begin. The heart is at first tubular, receiving posteriorly the venous trunks and giving off anteriorly the arterial trunks. It soon becomes twisted upon itself, so that the two extremities lie upon the same plane.

The heart now consists of a single auricle and a single ventricle. A septum, growing from the apex of the ventricle, divides into two cavities, a right and a left. The auricles also become partly separated by a septum, which is perforated by the foramen ovale. The arterial trunk becomes separated, by a partition, into two canals, which become, ultimately, the aorta and the pulmonary artery. The auricles are separated from the ventricles by incomplete septa, through which the blood passes into the ventricles.

Arteries.—The aorta arises from the cephalic extremity of the heart and divides into two branches, which ascend, one on each side of the intestine, and unite posteriorly to form the main aorta; posteriorly to these first aortic arches four others are developed, so that there are five altogether running along the visceral arches. The two anterior soon disappear. The *third arch* becomes the internal carotid and the external carotid; a part of the *fourth arch,* on the right side, becomes the subclavian artery, and the remainder atrophies and disappears, but on the left side it enlarges and becomes the permanent aorta; the *fifth arch* becomes the pulmonary artery on the left side. The communication between the pulmonary artery and the aorta, the *ductus arteriosus,* disappears at an early period.

Veins.—The venous system appears first as two short, transverse veins, the canals of Cuvier, formed by the union of the vertebral veins and the cardinal veins, which empty into the auricle. The inferior vena cava is formed, as the kidneys develop, by the union of the renal veins, which, in a short time, receive branches from the lower extremities. The subclavian veins join the jugular as the upper extremities develop. The heart descends in the thorax, and the canals of Cuvier become oblique; they shortly communicate by a transverse duct, which ultimately becomes the left innominate vein. The left canal of Cuvier atrophies and becomes a fibrous cord. A transverse branch now appears, which carries the blood from the left cardiac vein into the right, and becomes the vena azygos minor; the right cardiac vein becomes the vena azygos major.

Circulation of Blood in the Fetus.—The blood returning from the placenta, after having received oxygen and being freed from carbonic acid, is carried by the umbilical vein to the under surface of the liver; here a portion of it passes through the *ductus venosus* into the ascending vena cava, while the remainder flows through the liver and passes into the vena cava by the hepatic veins. When the blood is emptied into the right auricle, it is directed by the Eustachian valve through the foramen ovale, into the left auricle, thence into the left ventricle, and so into the aorta and to all parts of the system. The venous blood returning from the head and upper extremities is emptied, by the superior vena cava, into the right auricle, from which it passes into the right ventricle, and thence into the pulmonary artery. Owing to the condition of the lung only a small portion flows through the pulmonary capillaries, the greater part passing through the ductus arteriosus, which opens into the aorta at a point below the origin of the carotid and subclavian arteries. The mixed blood now passes down the aorta to supply the lower extremities, but a portion of it is directed, by the hypogastric arteries, to the placenta, to be again oxygenated.

At birth, the placental circulation gives way to the circulation of the adult. As soon as the child begins to breathe, the lungs expand, blood flows freely through the pulmonary capillaries, and the ductus arteriosus begins to contract. The foramen ovale closes about the tenth day. The umbilical vein, the ductus venosus, and the hypogastric arteries become impervious in several days, and ultimately form rounded cords.

TABLE OF PHYSIOLOGICAL CONSTANTS.

Mean **height** of male, 5 feet 6½ inches; of female, 5 feet 2 inches.

Mean **weight** of male, 145 pounds; of female, 121 pounds.

Number of **chemic elements** in the human body: from 16 to 18.

Number of **proximate principles** in the human body: about 100.

Amount of **water** in the body weighing 145 pounds: 109 pounds.

Amount of **solids** in the body weighing 145 pounds: 36 pounds.

Amount of **saliva** secreted in 24 hours: about 3½ pounds.

Function of **saliva:** converts starch into maltose.

Active principle of **saliva: ptyalin.**

Amount of **gastric juice** secreted in 24 hours: from 8 to 14 pounds.

Function of **gastric juice:** converts albumin into peptone.

Active principles of **gastric juice: pepsin** and **hydrochloric acid.**

Duration of **digestion:** from 3 to 5 hours.

Amount of **intestinal juice** secreted in 24 hours: about 1 pound.

Function of **intestinal juice:** converts cane sugar into dextrose and levulose; maltose into dextrose.

Amount of **pancreatic juice** secreted in 24 hours: about 1½ pounds.

Active principles of **pancreatic juice: trypsin, amylopsin,** and **steapsin.**

Functions:
1. Steapsin splits the neutral fats into fatty acids and glycerin.
2. Trypsin converts albumin into peptone.
3. Amylopsin converts starch into maltose.

Amount of **bile** poured into the intestines daily: about 2½ pounds.

Functions:
1. Assists in the emulsification of fats.
2. Stimulates the peristaltic movements.
3. Prevents putrefactive changes in the food.
4. Promotes the absorption of fat.

Amount of **blood** in the body: about $\frac{1}{13}$ of the body weight.

Size of **red corpuscles:** $\frac{1}{3200}$ of an inch.

Size of **white corpuscles:** $\frac{1}{2500}$ of an inch.

Shape of **red corpuscles:** circular biconcave discs.

Shape of **white corpuscles:** globular.

Number of **red corpuscles** in a cubic millimeter of blood (the cubic $\frac{1}{25}$ of an inch): 5,000,000.

Function of **red corpuscles:** to carry oxygen from the lungs to the tissues.

Frequency of the **heart's pulsation** a minute: 72 on the average.

Velocity of the **blood movement** in the arteries: about 12 inches a second.

Length of time required for the **blood** to make an entire circuit of the vascular system: about 20 seconds.

Amount of **air** passing in and out of the lungs at each respiratory act: from 20 to 30 cubic inches.

Amount of **air** that can be taken into the lungs on a forced inspiration: 110 cubic inches.

Amount of **reserve air** in the lungs after an ordinary expiration; 100 cubic inches.

Amount of **residual air** always remaining in the lungs: about 100 cubic inches.

Vital capacity of the **lungs:** 230 cubic inches.

Entire volume of **air** passing in and out of the lungs in 24 hours: about 400 cubic feet.

Composition of the **air:** nitrogen, 79.19; oxygen, 20.881, in 100 parts.

Amount of **oxygen** absorbed in 24 hours: 18 cubic feet.

Temperature of the **human body** at the surface: $98\tfrac{6}{10}$° F.

Amount of **urine** excreted daily: from 40 to 50 ounces.

Amount of **urea** excreted daily: 512 grains.

Specific gravity of **urine:** from 1015 to 1025.

Number of **spinal nerves:** 31 pairs.

Number of **roots of origin:** two; 1st, anterior, efferent; 2d, posterior, afferent.

Rate of transmission of **nerve force:** about 100 feet a second.

Number of **cranial nerves:** 12 pairs.

Nerves of special sense:

1. Olfactory, or first pair.
2. Optic, or second pair.
3. Auditory, or eighth pair.
4. Chorda tympani for anterior two thirds of tongue.
5. Branches of glosso-pharyngeal, or eighth pair, for posterior one third of tongue.

Motor nerves to **eyeball** and **accessory structures:** motor oculi, or third pair; pathetic, or fourth pair; abducens, or sixth pair.

Motor nerve to **facial muscles:** portio dura, facial, or seventh pair.

Motor nerve to **tongue:** hypoglossal, or twelfth pair.

Motor nerve to **laryngeal muscles:** spinal accessory, or eleventh pair.

Sensory nerve of the **face:** trigeminal, or fifth pair.

Sensory nerves of the **pharynx:** glosso-pharyngeal, or ninth pair.

Sensory nerves of the **lungs, stomach, etc.:** pneumogastric, or tenth pair.

Length of **spinal cord:** 16 to 18 inches; weight, 1½ ounces.

Point of decussation of **motor fibers:** at the medulla oblongata.

Point of decussation of **sensory fibers:** throughout the spinal cord.

Function of **anterolateral column of spinal cord:** transmit motor impulses from the brain to the muscles.

Function of the **posterior columns:** assist in the coördination of muscular movements.

Function of the **medulla oblongata:** controls the functions of insalivation, mastication, deglutition, respiration, circulation, etc.

Function of the **cerebellum:** center for the coördination of muscular movement.

Function of the **cerebrum:** center for intelligence, reason, and will.

Center for **articulate language:** third frontal convolution on the left side of cerebrum.

Number of coats to the **eye:** three: 1st, cornea and sclerotic; 2d, choroid; 3d, retina.

Function of **iris:** regulates the amount of light entering the eye.

Function of **crystalline lens:** refracts the rays of light so as to form an image on the retina.

Function of **retina:** receives the impressions of light.

Function of **membrana tympani:** receives and transmits waves of sound to internal ear.

Function of **Eustachian tube:** regulates the passage of air into and from the middle ear.

Function of **semicircular canals:** assist in maintaining the equipoise of the body.

Function of the **cochlea:** appreciates the shades and combinations of musical tones.

Size of **human ovum:** $\frac{1}{125}$ of an inch in diameter.

Size of **spermatozoa:** $\frac{1}{4000}$ of an inch in length.

Function of the **placenta:** acts as a respiratory and digestive organ for the fetus.

Duration of **pregnancy:** 280 days.

TABLE SHOWING RELATION OF WEIGHTS AND MEASURES OF THE METRIC SYSTEM TO APPROXIMATE WEIGHTS AND MEASURES OF THE UNITED STATES.

MEASURES OF LENGTH.

One Myriameter	= 10,000 meters	= 32,800	feet.
One Kilometer	= 1,000 “	= 3,280	“
One Hectometer	= 100 “	= 328	“
One Decameter	= 10 “	= 32.80	“
One METER	= the ten-millionth part of a quarter of the Meridian of the Earth.	= 39.368	inches.
One Decimeter	= the tenth part of 1 meter	= 3.936	“
One Centimeter	= the one-hundredth part of one meter	= 0.393 (⅖)	inch.
One Millimeter	= the one-thousandth part of one meter.	= 0.039 ($\frac{1}{25}$)	“

WEIGHTS.

One Myriagram	= 10,000 grams	= 26¾	pounds	Troy.
One Kilogram	= 1,000 “	= 2⅔	“	“
One Hectogram	= 100 “	= 3¼	ounces	“
One Decagram	= 10 “	= 2½	drams	“
One GRAM	= the weight of a cubic centimeter of water at 4° C.	= 15.434		grains.
One Decigram	= the tenth part of a gram	= 1.543 (1½)		“
One Centigram	= the 100th part of 1 gram	= 0.154 (⅙)		grain.
One Milligram	= the thousandth part of one gram	= 0.015 ($\frac{1}{64}$)		“

MEASURES OF CAPACITY.

One Myrialiter	= 10 cubic Meters or the measures of 10 Milliers of water	= 2,600	gallons.
One Kiloliter	= 1 cubic Meter or the measure of 1 Millier of water	= 260	“
One Hectoliter	= 100 cubic Decimeters or the measure of 1 Quintal of water	= 26	“
One Decaliter	= 10 cubic Decimeters or the measure of 1 Myriagram of water	= 2.6	“
One LITER	= 1 cubic Decimeter or the measure of 1 Kilogram of water	= 2.1	pints.
One Deciliter	= 100 cubic Centimeters or the measure of 1 Hectogram of water	= 3.3	ounces.
One Centiliter	= 10 cubic Centimeters or the measure of 1 Decagram of water	= 2.7	drams.
One Milliliter	= 1 cubic Centimeter or the measure of 1 Gram of water	= 16.2	minims.

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